DAHLGREN DIVISION
NAVAL SURFACE WARFARE CENTER
Dahlgren, Virginia 22448-5100

NSWCDD/TR-12/548

QUICK-EYE: EXAMINATION OF HUMAN PERFORMANCE CHARACTERISTICS USING EYE-TRACKING AND MANUAL-BASED CONTROL SYSTEMS FOR MONITORING MULTIPLE DISPLAYS

BY PETER SQUIRE
PATRICK MEAD
MELISSA SMITH
ROBERT COONS
ALLISON POPOLA

WARFARE SYSTEMS DEPARTMENT

MARCH 2013

Distribution statement A: Approved for public release; distribution is unlimited.

REPORT DOCUMENTATION PAGE						*Form Approved* *OMB No. 0704-0188*
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing this collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. **PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.**						
1. REPORT DATE *(DD-MM-YYYY)* 12 March 2013		**2. REPORT TYPE** Technical				**3. DATES COVERED** *(From - To)* 1 March 2013-31 March 2013
4. TITLE AND SUBTITLE Quick-Eye: Examination of Human Performance Characteristics Using Eye Tracking and Manual-Based Control Systems For Monitoring Multiple Displays						**5a. CONTRACT NUMBER**
						5b. GRANT NUMBER
						5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) Peter Squire, Patrick Mead, Melissa Smith, Robert Coons, Allison Popola						**5d. PROJECT NUMBER**
						5e. TASK NUMBER
						5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) AND ADDRESS(ES) Naval Surface Warfare Center Dahlgren Division (Code W62) Dahlgren, VA 22448-5100						**8. PERFORMING ORGANIZATION REPORT NUMBER** NSWCDD/TR-12/248
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)						**10. SPONSOR/MONITOR'S ACRONYM(S)**
						11. SPONSOR/MONITOR'S REPORT NUMBER(S)
12. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution unlimited.						
13. SUPPLEMENTARY NOTES						
14. ABSTRACT With operators monitoring an increasing number of digital information feeds from numerous devices, it is essential to quickly shift control among these devices when confronted with complex, asymmetric threat situations. These threats can manifest themselves quickly, leaving operators only a brief window of response time. Current switching methods rely on manual inputs, resulting in significantly slower response times. The authors describe the integration effort to combine eye-tracking technology into a multiple display information system, validation of the resulting system, and results of studies conducted to determine the performance impact to response time, accuracy, and user workload by using eye-tracking input instead of manual controls to switch control among multiple displays.						
15. SUBJECT TERMS Eye tracking human-computer interaction interface design human performance						
16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**		**19a. NAME OF RESPONSIBLE PERSON** Patrick Mead
a. REPORT UNCLASSIFIED	**b. ABSTRACT** UNCLASSIFIED	**c. THIS PAGE** UNCLASSIFIED	UL	64		**19b. TELEPHONE NUMBER** *(include area code)* 540-653-5186

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18

(THIS PAGE INTENTIONALLY LEFT BLANK)

FOREWORD

Military and law enforcement personnel are finding it increasingly necessary to monitor and control a greater number of devices while performing their duties. The need for methods to quickly and accurately shift attention and control between individual devices and their interface components is critical to responding to complex, asymmetric threat situations. Traditionally, manual interactions were used to execute these switching actions, which can take seconds. As many threats can occur quickly, leaving operators with only seconds to take action, the time associated with switching control between devices to respond to such threats may be the difference between success and failure.

In previous studies conducted by Popola, Squire, and Liu (2011), researchers sought to minimize the time and workload associated with switching between multiple devices by using eye-tracking technology rather than manual controls to perform the switching action. They predicted that such a method of interaction would result in faster response times, higher response accuracy, and lower operator subjective workload. The research team successfully integrated a desk-mounted eye tracker plus four pan-tilt-zoom networked cameras into a simulated surveillance system, called Quick-Eye. However, the results of the study were inconclusive; eye-tracking control performed no better or worse than a traditional manual switching method.

Given the results of the previous study and lessons learned during experimentation, it was determined that minor improvements to Quick-Eye were needed to reach system performance levels predicted for the two control types, and that minor changes to the experimental design and data collection methods would be needed to improve the accuracy and precision of the captured performance data.

This report covers the potential root causes for the unanticipated performance of the Quick-Eye system during previous research and identifies improvements made to the system and experimental data collection method. This report also highlights the human computer interaction predictions and results used to test and validate the performance of the Quick-Eye system, and the follow-on results of subsequent experimental trials.

Based on results gathered during the test and validation effort, it was determined the Quick-Eye system performed as well or better than the predicted performance levels for both the eye-tracking and manual based control methods, validating the success of the integration effort. Furthermore, the results of the experimental conditions confirmed that eye-tracking control outperformed manual control with respect to response time, accuracy, and operator subjective workload. Given these findings, it is recommended that further research be conducted to explore the integration and implementation of eye-tracking technology as a means of interface control, and to identify possible task and system use cases relevant to military and law enforcement command and control and combat systems.

This document has been reviewed by ________, Warfare Systems Department.

Approved by

DONALD L. BURNETT, Head
Warfare Systems Department

(THIS PAGE INTENTIONALLY LEFT BLANK)

CONTENTS

ILLUSTRATIONS

Figure Page

TABLES

Table Page

TABLES (CONT'D)

GLOSSARY

NSWCDD	Naval Surface Warfare Center, Dahlgren Division
KLM-GOMS	Keystroke-Level Model Gorals Operators Methods Section
NASA-TLX	National Aeronautics and Space Administration Taskload Index
Rt	response time

1.0 INTRODUCTION

With advancing technology, the average person is simultaneously exposed to more and more information, often through more than one interface. With each new interface introduced to their environment, users are presented with greater demands for their attention and interaction, spending more time switching between and managing these various interfaces.

This is particularly true for law enforcement and military personnel who are equipped with more technology than ever and are routinely tasked to monitor multiple security systems and sensor feeds, sift through troves of digital information, or control various remote systems and/or unmanned vehicles. With the addition of each new system, sensor, or video feed, users are required to manage and interact with increasing numbers of screens and information. Often, interaction with an individual screen or component of a system requires users to switch control between the interfaces of interest through a series of manual manipulations.

A prime example of such an interaction is that of a security operator switching between and manipulating the various camera feeds of a surveillance system. While a trained and experienced operator spends only a few seconds to switch control between feeds, it is often the aggregation of split-second reactions to the information presented through the system that make the difference between mission success and failure. So what if that operator could have nearly instantaneous control of a feed of interest simply by looking at it? How much time would be saved during execution of a task, how much faster and accurate would an operator be able to perform his duties if eye movements were used to switch control between these devices and displays rather than manual key strokes?

2.0 BACKGROUND

2.1 Literature Review

Traditionally, eye tracking has been primarily used in the research worlds of ophthalmology, neurology, and psychology as a tool for measuring and evaluating gaze location relative to an individual's field of view. The gaze information collected is used to identify oculomotor characteristics and abnormalities and their relationship to cognition and mental states [1]. Eye tracking has also seen limited use as an interaction device for individuals living with disabilities, such as cerebral palsy or paralysis, allowing them to communicate with and through computer interfaces using visual inputs to type and interact with the system [2].

There are two primary eye movements, fixations and saccades. Fixations can be described as the process where the eyes are focusing on an aspect in the environment for the purpose of gaining visual information. Saccades, conversely, are the rapid transition movements between fixations [3]. Hayhoe and Ballard reviewed several research studies investigating eye-movement patterns for various real-world tasks [4]. The central result was that eye fixations are tightly linked to the temporal (time related) evolution of a task, with very few task-irrelevant areas being fixated. Furthermore, eye movements are incredibly fast compared to other parts of the body and are theoretically the fastest physical input method [5]. As such, using eye movements may provide an intuitive and efficient means of switching between relevant screens when presented with multiple displays, as operators typically would not be looking at a screen unless it was relevant to the immediate task at hand.

As eye-tracking technology and gaze prediction methods have advanced, eye tracking has become an increasingly viable means of human-computer interaction. Specifically, those interfaces with an abundance of information and/or multiple display interfaces could benefit greatly from the speed and accuracy provided by eye tracking (see Figure 1). An investigation of the accidental deaths of 23 Afghan civilians during an American helicopter attack found that a Predator drone pilot had failed to communicate crucial information regarding the makeup of the crowd of villagers. The primary cause cited by the Army and Air Force for this failure was information overload. The operator and his team were responsible for monitoring the drone's multiple video feeds as well as communications with intelligence analysts and troops on the ground [6]. These types of critical work environments present daunting cognitive and physical challenges that leave the personnel in charge of these systems vulnerable to errors as a result of the increased workload, errors that in some instances can have deadly consequences. Eye tracking as a method of control may be a solution to decrease workload and increase efficiency, providing a natural and easy method to control and interact with these systems that alleviates cognitive and physical demands and decreases errors.

Figure 1. Military operator monitoring multiple screens (Shanker and Richtel, 2011)

2.2 Previous Results

In a previous study conducted by Popola, Squire, and Liu [7], researchers investigated eye tracking as a means of switching control between multiple displays. The study utilized a 2x2 factorial design examining the effects of "Control Method" (eye tracking or manual) and "Taskload" (low or high) on user performance with respect to response time, accuracy, and workload. The goal of the study was to create a surveillance system, called Quick-Eye, by integrating a commercial desk-mounted eye-tracking system with four networked cameras, and to evaluate human performance with the resulting system during a simulated threat-monitoring scenario. The experiment was designed to explore the benefits of using eye tracking as an input method and to determine the performance differences in response time, accuracy, and perceived workload between eye tracking and manual-based control methods under low and high taskloads.

The simulated threat-monitoring scenario consisted of participants acting as security operators conducting surveillance of office spaces using four video feeds. The participants were tasked with searching for potential security threats in the form of targets or distracters displayed on computer monitors located throughout the offices. Actors moved throughout each office space to cue the security operator when and where a possible threat might appear. The office computer monitors displayed either a target “D” or a distracter “G,” when the actors moved from one computer to the next. The security operator used directional arrows to pan the video feeds left and right as appropriate, and recorded a threat event using D or G, based on the threat displayed. After completing the task using each control method, users were asked to rate their perceived workload using the NASA-Taskload index (NASA-TLX) [8].

Unexpectedly, the results of this study showed no main or interaction effects for control method or taskload with respect to response time, accuracy, or overall workload. In addition, no significant differences in the means between eye tracking and manual-based control were found for response time, accuracy, or overall workload. While there were no statistically significant findings, the results did uncover a number of expected trends with respect to the performance of the eye-tracking control method. As anticipated, while using eye-tracking control, threat responses were faster, more accurate, and less workload compared to manual control, as illustrated in Figure 2.

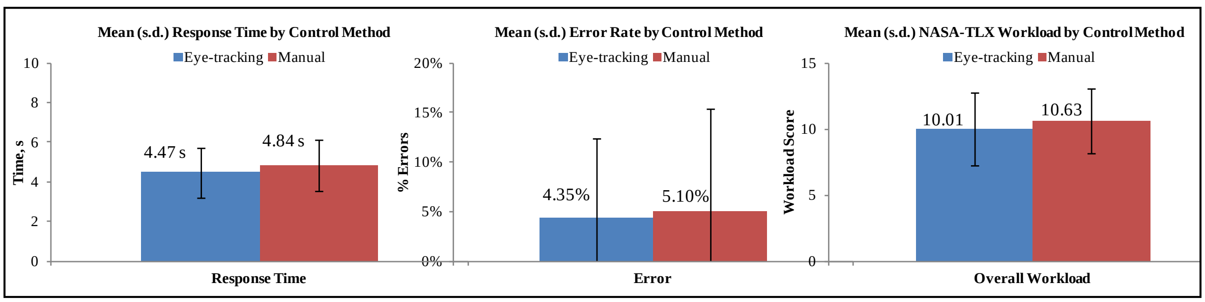

Figure 2. Mean Response Time, Error Rate, and Subjective Workload by Control Method

Given these trends, the lack of significant findings was attributed to limitations with the system and the experimental design. Quick-Eye, being a prototype, had yet to be fully tested and validated from a performance and usability perspective, introducing possible system error and variability. Furthermore, the system was only capable of capturing data at the precision level of one second, introducing potential rounding errors in the data. The precision level is particularly important as eye movements occur in fractions of a second.

In addition to confounding factors associated with Quick-Eye, the use of live actors and the lack of synchronized threat events was an additional source of variability. Actor movements were hard to synchronize, time, and repeat, causing variability across the scenarios. Threat events were displayed using timed slideshows that were also difficult to synchronize and time, requiring actors to simultaneously coordinate the start of multiple slideshows. The surveillance and threat systems were not integrated, requiring researchers to synchronize system and threat event timestamps after the data collection, exposing the data analysis to human data entry errors. Based on these identified limitations, further system developments and experimental refinements were necessary to uncover the true performance differences between eye tracking and manual-based control methods.

3.0 HARDWARE AND SOFTWARE INTEGRATION

3.1 Overview

The Quick-Eye system was developed and refined over a two-year period. During that time several experimental trials were conducted to test the hardware and software system and to determine user performance using eye-tracking technology to switch control between multiple displays. Initial integration efforts focused on developing a proof of concept system to demonstrate the feasibility of integrating multiple camera feeds with an eye tracking-controlled interface. Based on initial performance data collected, it was determined that further system and experimental design refinement was needed in order to accurately compare eye tracking and manual control. Eye tracking and manual control inputs were developed for the interface to allow for performance comparison between the two control methods. Following each design and experimental iteration, the Quick-Eye system was refined to improve the performance of both eye-tracking and manual control methods as well as the user interface.

An LC Technologies, Inc. Eyegaze eye tracker and Dell Inc. computer system were used as the platform for the Quick-Eye system, with system software and experiments coded in Microsoft Visual Studio C++ and AJAX. A desk-mounted eye tracker was selected for its ease of calibration and use. Desk-mounted eye tracking is an ideal setup for situations like security monitoring, providing a noninvasive interface that allows for less constricted user movement. The Eyegaze camera works by directing invisible infrared light at the eye and locating the pupil by detecting light reflected off the retina. Four pan-tilt-zoom Vivotek Inc. networked cameras were integrated with the system to form the Quick-Eye video surveillance component. Each camera feed was arranged in one of the four quadrants of the display and assigned a number 1 through 4 as a numerical reference for manually switching between the different camera views. Figure 3 illustrates this arrangement.

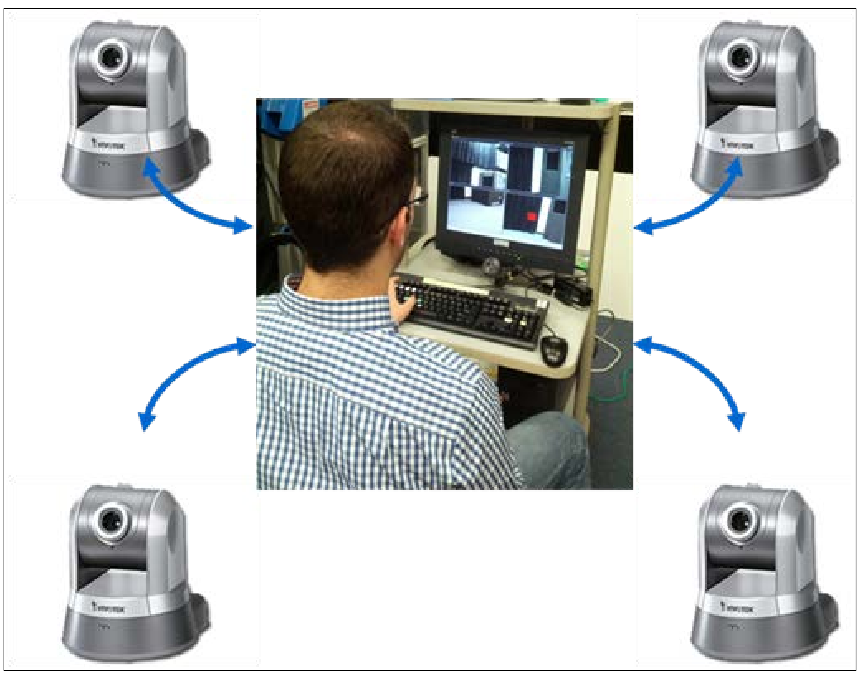

Figure 3. Quick-Eye System

3.2 System Integration

3.2.1 Phase I: Proof of Concept

Popola, Squire, and Liu's [7] efforts focused primarily on the initial development and integration of the eye-tracking system with four networked cameras and on developing the basic eye-tracking and manual-based control structures used in experimentation. A basic user interface consisting of four video displays was developed to provide a simulated surveillance environment (see Figure 4) as well as background key-logging and timestamp structures for capturing user performance data while using the system. The system allowed users to monitor the four independent camera feeds through one interface, controlling the camera direction using the left and right arrow keys, and responding to onscreen targets using the D and G keys. Control of the desired camera feeds was based on the control structure, eye tracking or manual. The experimental design required live actors to perform simulated office tasks while potential on-screen threats appeared on various monitors within the space.

Figure 4. Interface and Manual Controls

Manual mode required users to perform three keystrokes in response to an on-screen threat. The first keystroke selects the camera feed of interest using the numerical keys located in the upper row of the keyboard as illustrated in Figure 5, followed by a subsequent keystroke to confirm the choice. The final keystroke performed indicated the type of target observed, either D or G. Conversely, eye-tracking mode only required the user to look at the location of a target on the screen to gain control of the appropriate quadrant, and hit the identifying key relevant to the target type. In each mode, the system monitored users' actions by recording the camera selected, the target response key selected, and the time of each action. This data was then output to a text file for later evaluation. The key log provided the selection information and subsequent timestamp only when a user had confirmed the camera selection using the confirmation key (checkmark), and following the use of a target response key. The timestamps were recorded to the precision of one second.

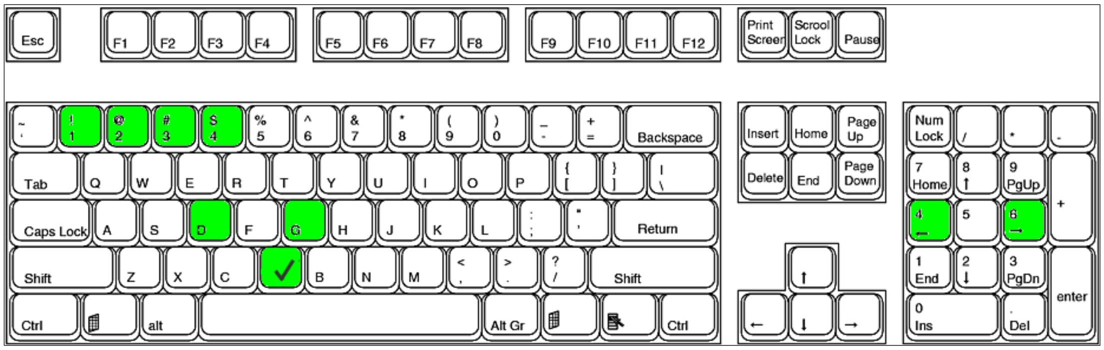

Figure 5. Keyboard Layout

Following the initial experimental trials, it was found that key logging and timestamp structures did not provide the level of fidelity and precision needed to capture exact performance of the two control methods, as some user actions were not captured or occurred in fractions of second. From a usability standpoint, many users felt that there wasn't sufficient feedback during the eye-tracking mode and, as a result, rated the workload higher. It was assumed that a lack of experience with eye tracking and of an on-screen indicator representing the location of their gaze caused some users to not trust the system was working and delaying their actions.

3.2.2 Phase II: Refinement and Validation

Based on the previous experimental results and lessons learned, several improvements were identified to further refine and improve the system's software performance, key logging and timestamp structures, experimental design, and interface feedback. In order to improve the system's computing speed and capabilities, individual software threads were developed to handle the system's individual functions. This allowed for faster, more reliable computing with less lag at the interface level. Introduction of the thread structure also allowed for easier integration of improved key logging and timestamps as well as the introduction of new features such as error logging and interface feedback.

Modifications were made to integrate the threat monitoring scenario with the system itself to improve the overall control and accuracy of the experimental design. The use of live actors and nonintegrated threats was eliminated to decrease experimental variability, improve the quality of data captured, and decrease experimental errors introduced from synchronization of user and threat event timestamp data. This was accomplished by creating an experimentation task thread that overlaid simulated threats on the interface, displaying targets in each of the camera quadrants for users to locate and identify (see Figure 6).

Figure 6. Experiment Overlay

Integrating the experiment into the system provided the ability for researchers to monitor the timing and sequence of events occurring on screen as well as the user actions in response to those events. The key logging and timestamp structures were redesigned to capture improved detail and to generate output formatted and ready for direct analysis following experimentation. Key logging was expanded to capture the type, timing, and location of all system events and user actions, and the precision of the timestamps was increased to the level of 1 ms. Table 1 shows that by recording the timing and location of the threat events, it was now possible to automate user error tracking, recording when a user switched to the wrong quadrant or selected the wrong threat response. The data output contained the threat event number, system/user action (Eg = Event G, Ug = User response G), a timestamp (hour, min, second, millisecond), the quadrant under control at the time of the event/action, the quadrant location of the threat, quadrant and value errors (0 or 1), and the time between events/actions. It was possible to validate the system performance and more accurately compare the two control methods by integrating the experiment into the actual system and improving the precision and accuracy of the data collected.

Table 1. Event/Action Timestamp and Error Data Log

Event	Action	Hour	Min	Sec	Ms	Current Quad	Destination Quad	Quad Error	Value Error	Time Diff
2	Eg	10	43	37	140	1	2	0	0	-
2	Switch	10	43	38	781	2	2	0	0	1.641
2	Ug	10	43	38	984	2	2	0	0	0.203

Following the improvements to the software structure, data logging system, and experimental design, efforts were made to improve the saliency and feedback of the eye-tracking control method. This was accomplished by incorporating a visual feedback icon representing the system's interpretation of the location of the user's gaze, as shown in Figure 7. The icon increased the saliency for both the users and researchers, allowing them to visually observe that the system was working as expected and improved user feedback by providing a real-time cue that the system had recognized users' shift in gaze to the quadrant they wished to control.

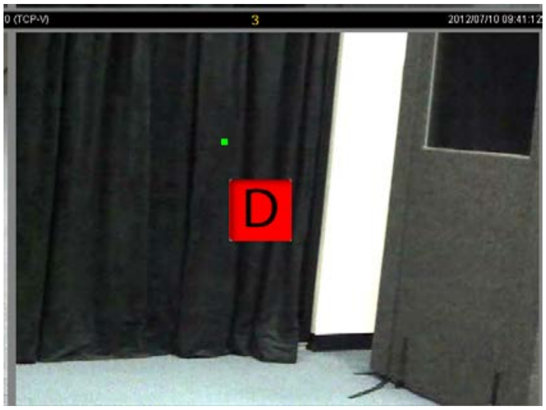

Figure 7. Eye-Tracking Control Visual Feedback Icon—Green Dot

After refining the system, a pilot study was conducted to determine the impact these changes had on system performance for each control method. The data collected from this pilot study was used to validate Quick-Eye's performance against predictive models of human performance and to conduct an initial investigation into the performance difference for each control method. Based on these findings, it was determined that the software and experimental design refinements were successful, and that user performance with the system while using both eye-tracking and manual-based controls was consistent with initial predictions. Based on results and user feedback gathered during the pilot study, additional usability changes were identified to further improve performance of the system and the two control methods.

3.2.3 Phase III: Usability Improvement

The usability changes identified in the pilot study highlighted disparities in the control structures and feedback between eye tracking and manual control methods. While the data reflected that both control methods performed as expected based on the predictive models, the comparison of performance with each control type showed discrepancies in the task and feedback structures that may have put manual control at a disadvantage.

Under manual control, the inclusion of a confirmation key added an additional step not required by eye-tracking control, adding subsequent time to complete a switching action. In order to make the comparison between eye tracking and manual control more even, the confirmation key was removed, which allowed users to switch to the display of interest with a single keystroke. Based on users' observations and feedback, many users spent time looking down at the keyboard to locate and select the correct quadrant key. As Figure 8 illustrates, the quadrant selection key layout was remapped from a linear to a spatial layout to improve manual control usability. Spatially mapping the keys to the displayed quadrants could eliminate the need to visually search for the correct key; therefore, decreasing the switch time, workload, and errors associated with the linear layout.

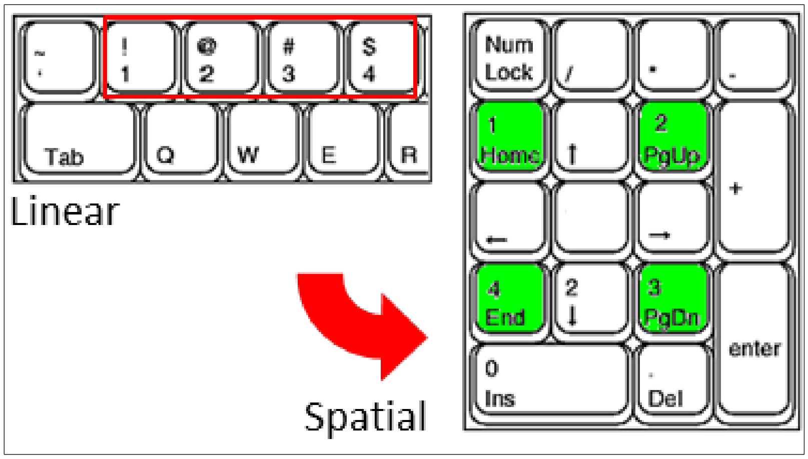

Figure 8. Manual Control Spatially Mapped Key Layout

In addition to control structure discrepancies, it was noted that the feedback structures for eye tracking and manual-based control were not equivalent. Manual control had no visual feedback, only the actual action of hitting the quadrant and confirmation keys provided users any indication of the quadrant under control. Many users also found the green dot somewhat distracting during eye-tracking control.

The green dot was abandoned and replaced with a shared visual feedback in an attempt to improve the saliency of both control methods and improve the equivalency of the comparison between them. A highlighted green border outlining the quadrant was added as feedback. This indicated the current quadrant under control for both control methods (see Figure 9). By providing the highlight, users were subtly informed the system was responding as intended, eliminating any possible condition differences that could impact performance results. The border also decreased user distraction during eye-tracking control by shifting the feedback out of users' focal vision to their periphery vision.

Figure 9. Improved User Feedback—Green Border

4.0 METHODOLOGY

4.1 Overview

The overall objective of this study was to investigate the feasibility and effectiveness of using eye tracking as an input method for gaining control of multiple displays during a surveillance monitoring scenario. In order to establish the feasibility and effectiveness it was necessary, using eye-tracking and manual-based control methods, to determine the:

a. Baseline performance of eye tracking and manual-based control methods; validate system performance against predictive models of human-computer interaction performance
b. Relationship between response time and control type under varying task conditions
c. Relationship between accuracy and control type under varying task conditions
d. Relationship of user-perceived workload under varying task conditions

A two-phased approach was used, consisting of a validation phase, which assessed system performance and piloted the experimental design, and an experimental phase, where experimental trials were conducted to determine the impact of control method on user performance.

4.2 Participants

Participants were recruited through a distribution e-mail to targeted internal Naval Surface Warfare Center, Dahlgren Division (NSWCDD), departments and personal interaction (see Appendix A). Participants received no direct or indirect benefit for participating in this study. No coercion was used to solicit participation. Prior to beginning any experiment, participants were given an informed consent form and walked through the experimental procedure (see Appendix B). Following their consent, participants were administered a brief demographics questionnaire (see Appendix C) to capture basic gender, age, and vision (corrected vs. uncorrected) information.

4.3 Test Setup

The study was conducted in the NSWCDD Human Performance Laboratory. The experiment setup included a desktop computer with an integrated desk-mounted eye tracker. The setup also included four networked pan-tilt zoom cameras, providing a simulated surveillance feed. Participants used a standard keyboard to control camera direction, and used either the eye tracker or keyboard for controlling each camera feed based upon the experimental condition. The eye tracker was calibrated prior to use during the trials.

4.4 Phase I: System Validation

A validation study was conducted prior to experimental trials, verifying that the experimental design was capable of capturing the data necessary for comparing the performance levels of the two control methods, and to ensure system performance matched that of predicted models of performance. To validate the system performance, user data was collected and evaluated against the Keystroke-Level Model Goals Operators Methods Selection (KLM-GOMS).

The KLM-GOMS is one of numerous tools used in the design and evaluation of human-computer interaction with a system [8]. Specifically, the KLM-GOMS is a simplified version of the more complex GOMS model, using pre-established operators to predict the time to execute each component of a given task.

With respect to the Quick-Eye system, there are three relevant action operators used in switching control between multiple displays: mental preparation time, eye movement, and keystrokes. The KLM-GOMS model prediction for pressing a button on a keyboard, a keystroke operator (K), is 0.28 seconds for the average non-secretarial typist, and 1.2 seconds for a mental preparation operator (M) [9]. Eye movements, in comparison, are the fastest with an eye movement operator (E) prediction of 0.03 seconds [10]. Using these predicted times, estimates of event response time during the visual search task were determined for eye tracking and manual-based control, with predictions of 1.51 seconds and 2.07 seconds respectively as indicated in Table 2.

Table 2. KLM-GOMS Predictions for Manual vs. Eye Movement Camera Switches

Eye Tracking Camera Switching		**Manual Camera Switching**	
Mental Preparation [M]	1.20 s	Mental Preparation [M]	1.20 s
Eye Movement to camera view to be engaged [E]	0.03 s	Eye Movement to camera view to be engaged [E]	0.03 s
Keystroke of presented letter [K]	0.28 s	Keystroke of button associated with desired camera [K]	0.28 s
		Keystroke of Confirmation Button [K]	0.28 s
		Keystroke of presented letter [K]	0.28 s
Total:	1.51 s	Total:	2.07 s

4.4.1 Task Design

A single factor, Control Type (eye tracking, manual), repeated measures experimental design was used in the validation of the Quick-Eye system, with participants completing an event-driven, scripted visual search task consisting of 71 events, using both eye tracking and manual input methods. Data collected from the scripted task was analyzed and compared against KLM-GOMS performance predictions.

The visual search task was coded in Microsoft Visual Studio C++, presenting G and D event icons overlaid onto the Quick-Eye surveillance interface. This is illustrated in Figure 10. The task consisted of presenting users with a single event, a red icon, representing a target or distracter in the center of one of the four quadrants. Individual timestamps, measured to the precision of 1ms, were captured for each event occurrence and subsequent actions users took to respond to events throughout the task. Each timestamp also included an error log that recorded incorrect user quadrant switches or target/distracter responses. The timestamps and error log were then used to automatically calculate event and user response speed and accuracy.

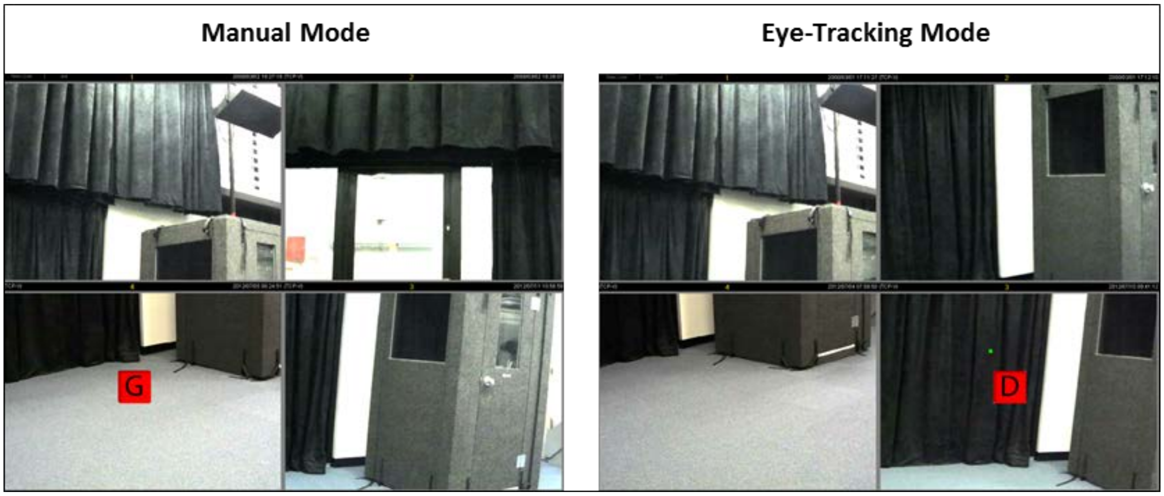

Figure 10. Event Occurrence in Manual and Eye-Tracking Modes

Under manual control, the keyboard was the sole input method for gaining control of individual camera feeds and responding to the appropriate target or distracter (see Figure 10, Manual Mode). Users identified the quadrant based on the numeric label and pressed the corresponding numerical key at the top of the keyboard, followed by a confirmation key. Users then hit the response key associated with the presented icon, with the next event occurring immediately after a correct response.

Using the eye tracking-based control method, users simply looked at or near the icon presented within a quadrant, and hit the corresponding response key of the target or distracter. While using the eye tracking-based control, users were presented with a small green feedback dot, increasing saliency of their gaze location and reassuring them the system was active and responding correctly (Figure 10, Eye-Tracking Mode). To prevent accidental quadrant switches because of inadvertent eye movements, a 50 pixel invisible buffer was established inside the border of each quadrant. This buffer acted as an invisible threshold, requiring the user to look at or near the icon to gain control of the camera quadrant, preventing inadvertent switches when looking at or near the borders.

4.5 Phase II: Experiment

Phase II of the study conducted experiments using the validated Quick-Eye system to determine the impact of control type on user speed, accuracy and perceived workload under varying task conditions. A 2 (Control Method) x 2 (Event Timing) x 2 (Taskload) within subjects repeated measures experimental design was used evaluating:

a. Experimental task performance variables
   (1) Average event response time (s)
   (2) Average quadrant switch time (s)
   (3) Average target response time (s)
   (4) Quadrant error rate (%)
   (5) Value error rate (%)
b. Subjective workload ratings
   (1) Overall subjective workload
   (2) Mental and physical workload
   (3) Temporal demand
   (4) Performance level
   (5) Effort and frustration level

Similarly to the validation study, users were asked to complete a series of visual search tasks using both the eye tracking and manual controls. Users were again presented with targets and distracters and asked to quickly and accurately respond to threat events. Unlike the validation study additional factors, Event Timing and Taskload were manipulated to test each control method under varying conditions similar to those found in other real-world tasks. For each control condition, users were presented with one of two levels for Event Timing, either event driven or randomly timed threat occurrences, and one of two levels of Taskload, low or high.

Event Timing manipulated how and when individual threat events occur. Event-driven timing consisted of events triggered by the completion of the previous event, with a new threat event appearing the moment a user responded to the previous event (time between events = 0 sec). Randomly timed threat occurrences required a vigilance component with randomized time intervals between the occurrences of each event. Users were required to wait an unknown and varying amount of time after responding to the previous event before the appearance of the next event (time between event = 0–4 sec).

Taskload was varied for each combination of Control Method and Event Timing, with users completing 50 events for low taskload conditions and 100 events for high taskload conditions. Taskload was intended to represent varying levels of workload and task duration, with high taskload placing greater demands on users than low taskload.

4.6 Statement of Hypothesis

4.6.1 Main Effects

1. *Control Method* will have a significant effect on event response time, with faster response times using eye gaze-based control
2. *Control Method* will have a significant effect on event quadrant selection and target response accuracy, with more accurate quadrant selection and target response using eye gaze-based control
3. *Control Method* will have a significant effect on overall perceived workload, with lower overall perceived workload using eye-based control
4. *Event Timing* will have a significant effect on event response time, with faster response times under event-driven timing conditions
5. *Event Timing* will have a significant effect on event quadrant selection and target response accuracy, with more accurate quadrant selection and target response using eye gaze-based control
6. *Event Timing* will have a significant effect on overall perceived workload, with lower overall perceived workload under event-driven timing conditions
7. *Taskload* will have a significant effect on event response time, with faster response times under low task-loading conditions
8. *Taskload* will have a significant effect on event quadrant selection and target response accuracy, with more accurate quadrant selection and target response using eye gaze-based control
9. *Taskload* will have a significant effect on overall perceived workload, with lower overall perceived workload under low task-loading conditions

4.6.2 Second Order Interaction Effects

10. *Control Method x Event Timing* will have no significant effect on event response time, quadrant or target response accuracy, or overall workload
11. *Control Method x Taskload* will have no significant effect on event response time, quadrant or target response accuracy, or overall workload
12. *Event Timing x Taskload* will have no significant effect on event response time, quadrant or target response accuracy, or overall workload

4.6.3 Third Order Interaction Effects

13. *Control Method x Event Timing x Taskload* will have no significant effect on event response time, quadrant or target response accuracy, or overall workload

5.0 RESULTS

5.1 System Validation

5.1.1 Participation

Twelve participants, five males and seven females, ranging in age from 21 to 50 (average age 34) years, with normal (20/20) or corrected-to-normal vision, participated in the study. Prior to collecting user data, each participant was provided with informed consent and description of the experimental task and each control type. Participants were informed the purpose of the task was to quickly and accurately switch to the quadrant with the displayed threat and press the corresponding response key, with a subsequent threat appearing following a correct response.

5.1.2 Keystroke-Level Model Goals Operators Methods Selection

Validation of the Quick-Eye system was conducted by comparing the user performance data collected using the Quick-Eye system against human computer interaction KLM-GOMS performance predictions (see Figure 11). For the integration to be considered a success, the mean user event response times for each control method needed to be less than or equal to the predicted times, 1.51 sec for eye-tracking control and 2.07 sec for manual control. Participant event response times were averaged for each of the 72 events then aggregated to determine the overall mean event response time (Rt) for each control method.

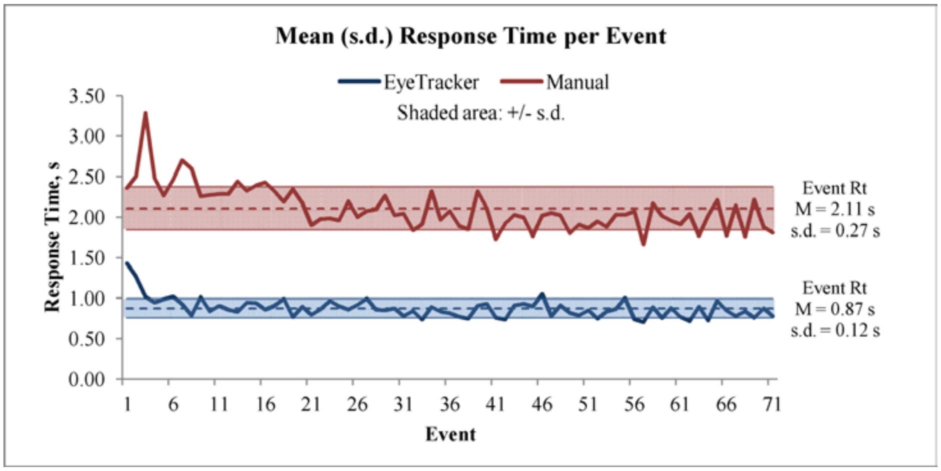

Figure 11. Rt per Event over the Course of Task

The overall mean event Rt for each control method was then compared to the KLM prediction using a one sample t-test at alpha of 0.05. The mean event response time for eye tracking-based control (M = 0.87 s, SD = 0.12 s) was found to be significantly less than the predicted 1.51 sec, t (70) = -45.14, $p < 0.001$. The mean event response time for manual control (M = 2.11 s, SD = 0.27 s) was found not to be significantly different than the predicted 2.07 sec, t (70) = 1.20, p = 0.115. These results confirm that each control method performed at or better than their KLM-GOMS prediction, validating the Quick-Eye system capable of the desired levels of user performance.

5.1.3 Pilot Experimental Evaluation

In addition to validating Quick-Eye's performance, an initial exploration into the performance of each control method was conducted to evaluate the experimental design and gain initial insights with respect to the following hypotheses:

Hypothesis 1: Control type will have a significant effect on response time, with the eye tracking-based control having significantly faster response times than manual control.
Hypothesis 2: Control type will have a significant effect on perceived workload, with the eye tracking-based control having significantly lower perceived workload than the manual control.
Hypothesis 3: Control type will have a significant effect on accuracy, with the eye tracking-based control having significantly fewer errors than the manual control.

5.1.4 Event Response Time

An initial comparison of the eye tracking-based and manual control methods was performed using a paired t-test comparing the mean event response times of all 12 participants. Test results found the methods to be significantly different, t (11) = -11.14, p < 0.000, with the eye tracking-based control method (M = 0.87 s, SD = 0.12 s) being faster than the manual control method (M = 2.11 s, SD = 0.27 s), confirming Hypothesis 1.

A more detailed examination of individual user actions during an event response revealed the time savings associated with eye tracking-based control occurred during the switch from one quadrant to a quadrant of interest (see Figure 12). Comparing the mean time to perform a switch action using eye tracking-based control (M = 0.23 s, SD = 0.06 s) to that of manual control (M = 1.66 s, SD = 0.32 s) resulted in a significant difference, t (11) = -19.12 , p < 0.001, with eye tracking-based control switching taking approximate 1.5 sec less time to perform.

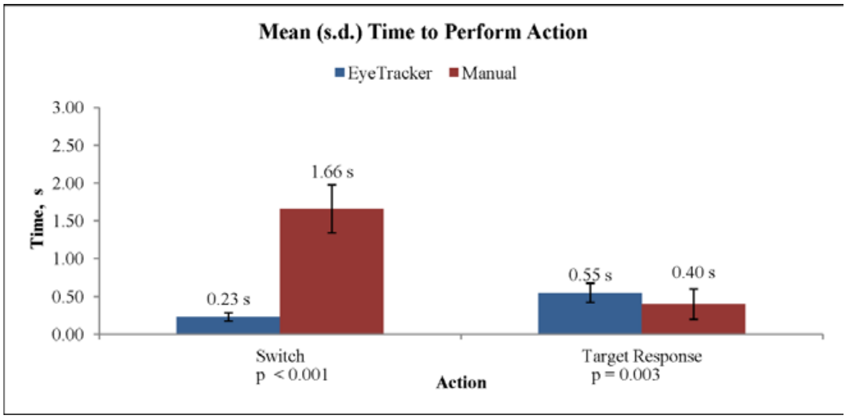

Figure 12. Mean Time to Perform Action

Interestingly, the time to complete a target response was significantly different between eye-tracking and manual control, t (11) = 3.46, p =0.003 with manual control target response (M = 0.40 s, SD = 0.20 s) being slightly faster than eye-tracking control target response (M = 0.55 s, SD = 0.13 s). The cause of this difference is not clear; however, a possible explanation could depend on when target response mental preparation occurs, and how much mental preparation time is needed during the target response action for each control method.

5.1.5 Subjective Workload

An examination of the NASA-TLX subjective workload ratings showed slight differences in the perceived workload for each control method (see Figure 13). Using a paired t-test, mental demand t (11) = -3.84, p = 0.001, physical demand t (11) = -1.77, p = 0.052, effort t (11) = -2.19, p = 0.025, and frustration level t (11) = -4.08, p < 0.001 were found to be significantly different and lower for the eye-gaze control method as compared to manual control. A comparison of temporal demand $t\ (11) = 0.31$, $p = 0.380$, and performance, $t\ (11) = -1.51$, $p = 0.08$ for each control method resulted in no significant differences. While not conclusive, eye-tracking control appears to have a lower perceived workload compared to manual control, consistent with Hypothesis 2.

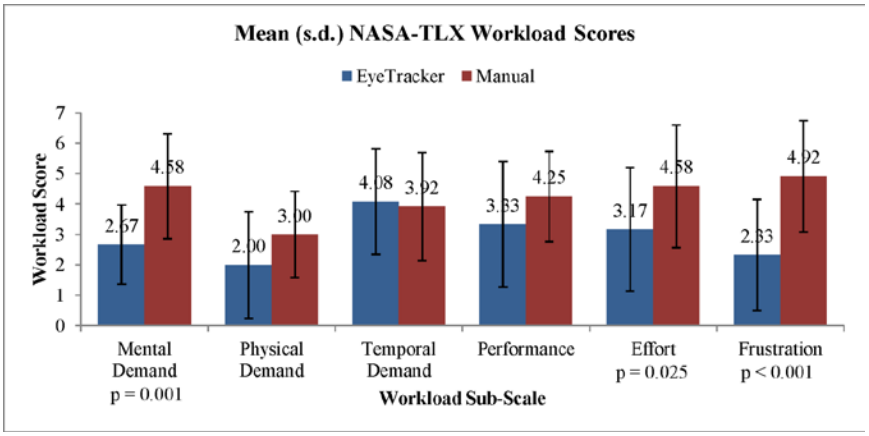

Figure 13. Mean Workload Scores

5.1.6 Error Rate

Two error types were recorded: quadrant errors, which occurred when a participant switched to an incorrect quadrant; and value errors, which occurred when a participant selected an incorrect response to a target or distracter. Eye tracking-based control resulted in a mean quadrant error rate of 3.52 percent (*SD* = 5.01%) and mean value error rate of 2.82 percent (*SD* = 2.88%), with manual control resulting in a quadrant error rate of 3.17 percent (*SD* = 4.58%) and value error rate of 2.35 percent (*SD* = 2.77%), as shown in Figure 14.

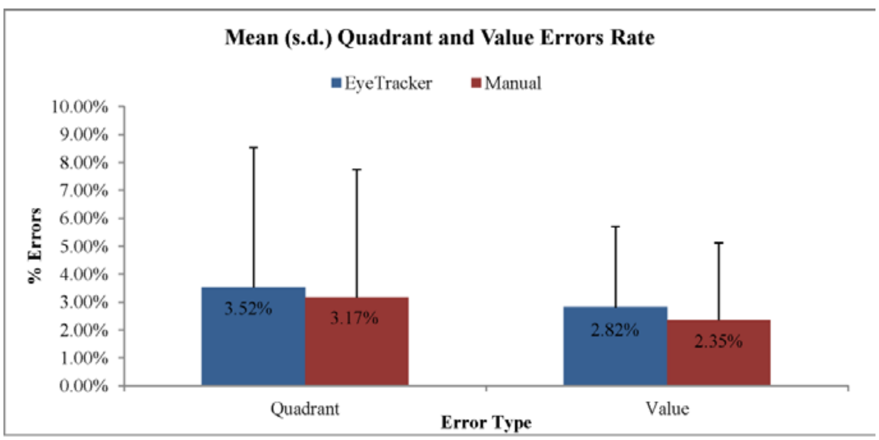

Figure 14. Mean Error Rate

Using paired t-test, no significant differences were found in quadrant error rates $t\ (11) = -0.27$, $p = 0.79$ or value error rates $t\ (11) = -0.46$, $p = 0.65$ between eye-tracking and manual-based control. These results do not support the third hypothesis, and suggest that quadrant and value error rates are not lower for eye-tracking control. While this result is unexpected, it does indicate there is no significant decrement in performance for the given task, which may not hold true for more complex or cognitively demanding tasks. Further study is needed to determine if increased cognitive complexity and/or task demand will further impact performance with either method of control.

5.2 Experimental Evaluation

5.2.1 Participation

Eleven participants, six males and five females, ranging from ages 24 to 48 (average age 31) years, with normal (20/20) or corrected-to-normal vision, participated in the study. Prior to collecting user data, each participant was provided with informed consent and a description of the experimental task and each control type. Participants were informed the purpose of the task was to quickly and accurately switch to the quadrant with the displayed target and press the corresponding response key, with a subsequent target appearing following a correct response.

5.2.2 Analysis of Variance (ANOVA)

A 2 (Control Method) x 2 (Event Timing) x 2 (Taskload) analysis of variance (ANOVA) was calculated for each of the following dependent measures:

a. Experimental task performance variables
   (1) Average event response time (s)
   (2) Average quadrant switch time (s)
   (3) Average target response time (s)
   (4) Quadrant error rate (%)
   (5) Value error rate (%)
b. Subjective workload ratings
   (1) Overall subjective workload
   (2) Mental and physical workload
   (3) Temporal demand
   (4) Performance level
   (5) Effort and frustration level

5.2.3 Event Response Time

An ANOVA, assuming alpha of 0.05, was used to examine the effects of Control Method, Event Timing, and Taskload on event response time (see Table 15 in Appendix E). Significant main effects exist for two factors, Control Method F (1, 10) = 82.68, p < 0.001 and Event Timing F (1, 10) = 12.56, p = 0.005), as well as their second order interaction F (1, 10) = 6.828, p = 0.026, as indicated in Table 3. No significant main effect exists for Taskload relative to event response time, which does not support Hypothesis 7. In addition, no second or third interaction effects were found for Taskload with respect to event response time supporting hypotheses 11 through 13 with respect to event response time.

Table 3 ANOVA—Event Response Time Significant Effects

Source	Sum of Squares	df	Mean Square	F	Sig.
Control Method	11.110	1	11.110	82.680	0.000
Event Timing	0.200	1	0.200	12.560	0.005
Control Method * Event Timing	0.168	1	0.168	6.828	0.026

The significant main effects, as illustrated in Figure15, can be seen by plotting the mean event response time by both Control Method and Event Timing. The slope for Control Method plot shows a greater impact to mean response time compared to the impact from Event Timing.

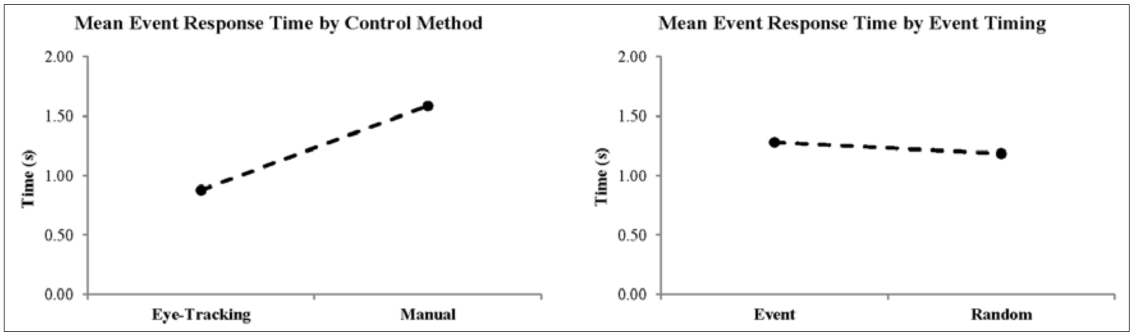

Figure 15. Plot of Significant Main Effects for Mean Response Time by Control Method and Event Timing

More detailed comparison of each control method shows a significant difference in mean response time, t (10) = -9.08, $p < 0.001$ with eye tracking-based control (M = 0.88 s, SD = 0.04 s) responding on average 0.71 sec faster than manual-based control (M = 1.59 s, SD = 0.11 s), supporting Hypothesis 1 (refer to Figure 15). Plotting event response time over the course of the simulated surveillance task shows eye tracking allows for faster, more consistent response times, as shown in Figure 16.

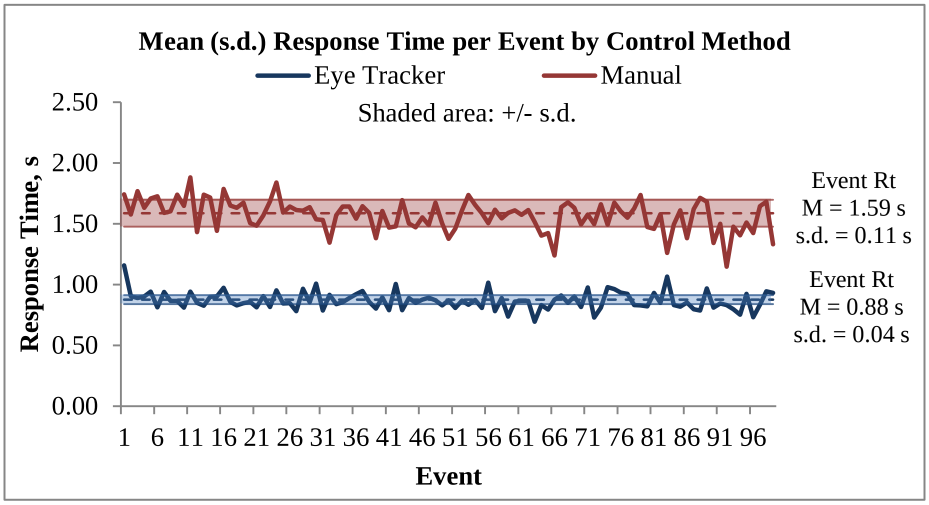

Figure 16. Mean Event Response Time per Event by Control Method

Exploring the main effect plot for Event Timing shows a significant difference in mean event response time, t(10) = 3.53, p = 0.002 with randomly occurring threat event (M = 1.184 s, SE = 0.075 s) response times being *faster* than event driven occurrences (M = 1.28 s, SE = 0.074 s) (refer to Figure 15). While the existence of a significant main effect for Event Timing supports Hypothesis 4, the outcome of that effect did not support the prediction that event driven threat occurrences would result in faster response times. To better understand this outcome, a more detailed analysis looked at the second order interaction effects.

The existence of a second order interaction effect between Control Method and Event type does not support Hypothesis 10 with respect to event response time. The plot of the interaction shows a noticeable negative slope for manual control and a slope of approximately zero for eye-tracking control (see Figure 17). During manual-based control, response times were significantly slower for event-driven threat occurrences (*M* = 1.68 s, *SD* = 0.36 s) compared to randomly timed threat occurrences (*M* = 1.50 s, *SD* = 0.39 s), t (10) = 3.43, p = 0.003, and not significantly different during eye tracking-based control. This demonstrates that the interaction effect between Control Method and Event Timing extends only to the manual-based control condition. In addition, this shows that the significant main effect for Event Timing is not independent of control method and is driven by the interaction effect with the manual-based control method.

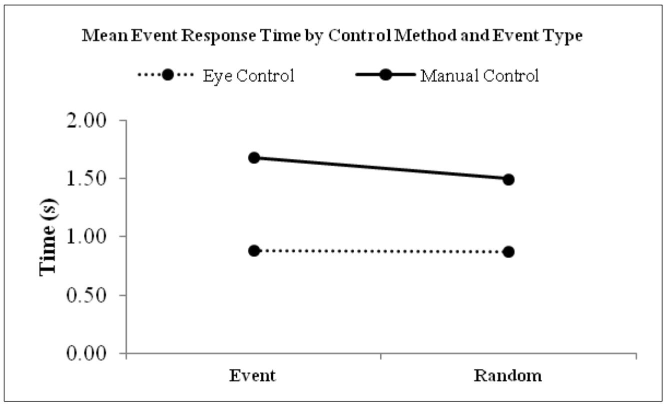

Figure 17. Plot of Significant Second Order Interaction Effect for Mean Response Time (Control Method x Event Timing)

5.2.4 Quadrant Switch and Target Response Time

Following the analysis of the mean event response time, performance times for switching between quadrants and responding to the targets were broken out and analyzed for each of the main effects, Control Method and Event Timing (see Tables 16 and 17 in Appendix E). It was assumed the majority of time savings resulted from time saved during the switch from quadrant to quadrant, with target response times being equivalent, and that switching and target response times would be faster during randomly driven event conditions.

In Figure 18, a plot of the mean switch and target response times by Control Method shows that the time savings associated with eye tracking based control occurred during the switch from one quadrant to the next. Comparing the mean time to perform a switch action using eye tracking-based control (*M* = 0.21 s, *SD* = 0.03 s) to that of manual control (*M* = 1.05 s, *SD* = 0.24 s) resulted in a significant difference, t (10) = -11.85 , $p < 0.001$, with eye tracking-based control switching occurring approximate 0.84 sec faster. No significant difference was found for target response times, as expected.

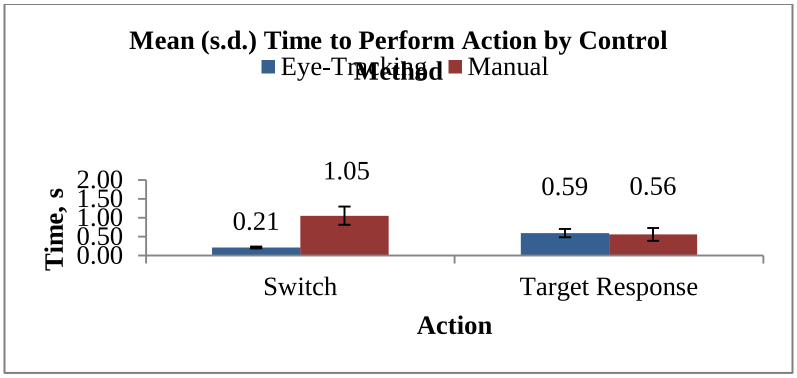

Figure 18. Mean Time to Perform Action by Control Method

A plot of the mean switch and target response times by Event Timing in Figure 19 again shows that user actions during randomly timed threat occurrence conditions were faster. Comparing the mean time to perform a switch action during the event-driven condition (M = 0.65 s, SD = 0.14 s) to that of random driven (M = 0.61 s, SD = 0.13 s) resulted in a significant difference, t (10) = 3.22, p = 0.004, with switching occurring approximately 0.04 sec faster. Comparing the mean time to perform a target response action during the event-driven condition (M = 0.60 s, SD = 0.13 s) to that of random driven (M = 0.55 s, SD = 0.13 s) resulted in a significant difference, t (10) = 3.65, p = 0.002, with target responses occurring approximately 0.05 sec faster.

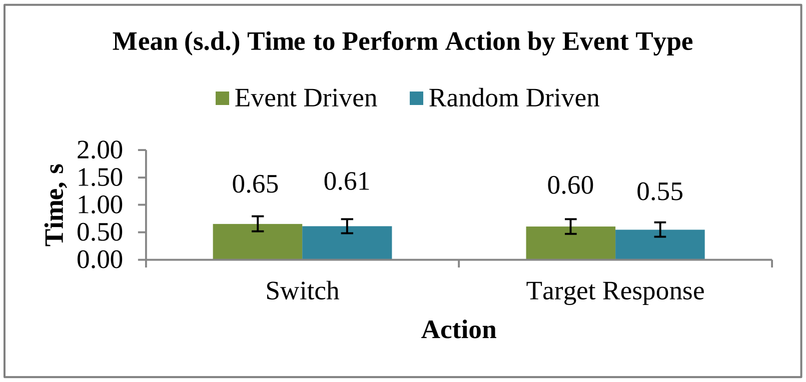

Figure 19. Mean Time to Perform Action by Event Timing

A plot of the mean switch and target response times by Control Type and Event Timing in Figure 20 again shows that user actions during random driven event conditions were fastest for eye tracking. Comparing the mean time to perform a switch action using eye tracking during the event-driven condition (M = 0.22 s, SD = 0.03 s) to that of random driven (M = 0.20 s, SD = 0.03 s) resulted in a significant difference, t (10) = 2.32, p = 0.02. Comparing the mean time to perform a switch action using manual control during the event-driven threat events (M = 1.08 s, SD = 0.26 s) to that of randomly occurring threat events (M = 1.02 s, SD = 0.25 s) resulted in a significant difference, t (10) = 2.75, p = 0.01. Comparing the mean time to perform a target response action using manual control during the event-driven condition (M = 0.61 s, SD = 0.18 s) to that of random driven (M = 0.51 s, SD = 0.19 s) resulted in a significant difference, t (10) = 2.83, p = 0.009. No significant difference was found for target response during different event conditions when using eye tracking.

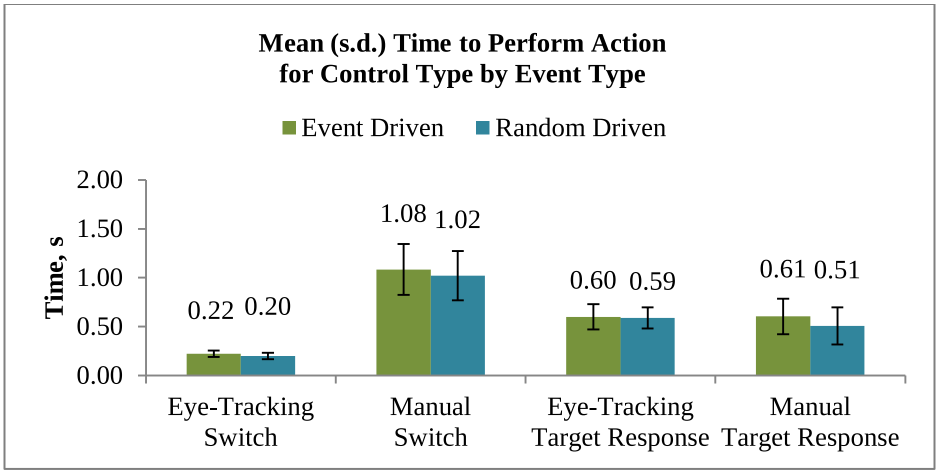

Figure 20. Mean Time to Perform Action by Control Type by Event Type

5.2.5 Error Rates

No significant main effects or interaction effects were found for Control Method, Event Timing, and Taskload for quadrant errors or target response errors (see Tables 18 and 19 in Appendix E). This result does not support our hypotheses that Control Method, Event Timing, and Taskload (hypotheses 2, 5, 8) would have a significant effect on quadrant and target accuracy. This does, however, support our hypotheses that the interaction between Control Method, Event Timing, and Taskload (hypotheses 10–13) with respect to accuracy would have no effect. While there were no significant effects found, additional analysis was conducted to determine if any performance trends existed across condition levels.

A plot of the mean percent error by Control Method shows that users switched more accurately when using eye tracking-based control (see Figure 21). Comparing the mean percent error for quadrant selection when using eye tracking-based control (M = 1.41%, SD = 1.24%) to that of manual control (M = 2.32%, SD = 1.31%) resulted in a nearly significant difference, t (10) = -1.62, p = 0.068. Comparing the mean percent error for target response when using eye tracking-based control (M = 4.59%, SD = 3.29%) to that of manual-based control (M = 4.30%, SD = 2.41%) resulted in no significant difference, t (10) = 0.29, p = 0.39.

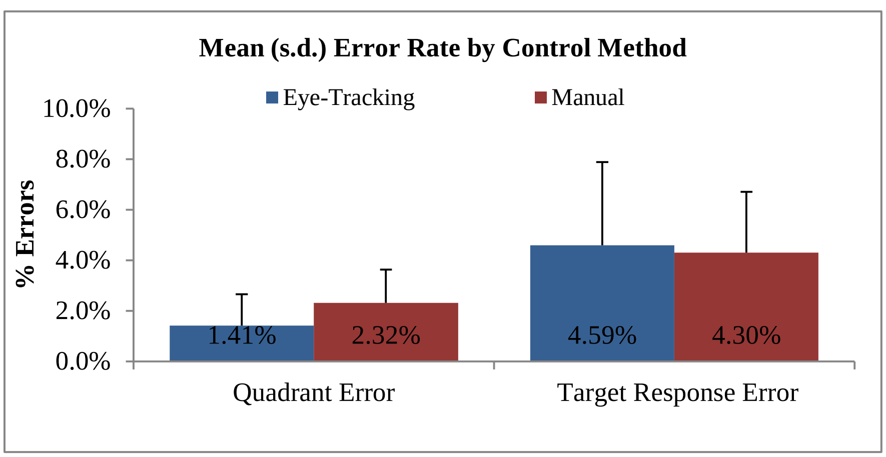

Figure 21. Mean Quadrant and Target Response Error Rates by Control Method

In Figure 22, a plot of the mean percent error by Event Timing shows that users were slightly more accurate in switching and responding to event-driven threat occurrences. Comparing the mean percent error for quadrant selection during event-driven threats (*M* = 1.82%, *SD* = 0.99 %) to that of random driven (*M* = 1.91%, *SD* = 1.51%) resulted in no significant difference, t (10) = -0.16, $p = 0.44$. Comparing the mean percent error for target response when using eye tracking-based control (*M* = 3.98%, *SD* = 2.42%) to that of manual control (*M* = 4.91%, *SD* = 3.03%) resulted in no significant difference, t (10) = -1.10, $p = 0.15$.

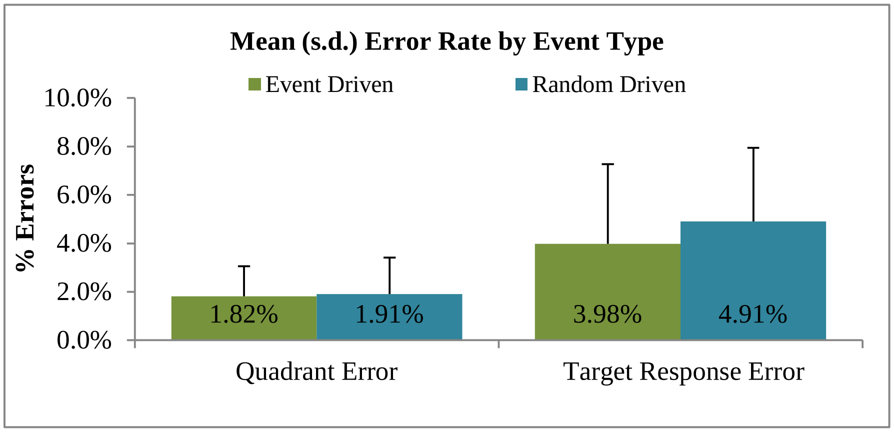

Figure 22. Mean Quadrant and Target Response Error Rates by Event Type

A plot of the mean percent error by Taskload in Figure 23 shows a trend that users were more accurate in switching and responding to threats in low taskload conditions. Comparing the mean percent error for quadrant selection for low Taskload (*M* = 1.55%, *SD* = 1.08 %) to that of high Taskload (*M* = 2.18%, *SD* = 1.30%) resulted in no significant difference, t (10) = -1.28, $p = 0.11$. Comparing the mean percent error for target response when using eye tracking-based control (*M* = 4.36%, *SD* = 2.11%) to that of manual control (*M* = 4.52%, *SD* = 2.85%) resulted in no significant difference, t (10) = -0.31, $p = 0.38$.

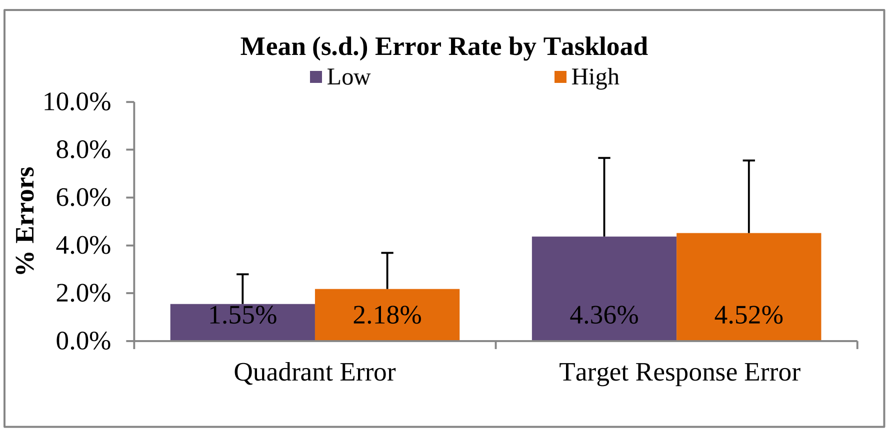

Figure 23. Mean Quadrant and Target Response Error Rates by Taskload

5.2.6 Subjective Workload

Examining the effects of Control Method, Event Timing, and Taskload on NASA-TLX subjective workload ratings found several main and interaction effects (see Tables 20–26 in Appendix E). The results of the ANOVA indicate significant main effects exist for Control Method F (1, 10) = 5.146, $p = 0.002$ and Taskload F (1, 10) = 0.455, $p < 0.001$) with respect to overall workload, supporting hypotheses 3 and 9. No significant main effect was found for Event

Timing with respect to overall workload, which does not support Hypothesis 6. However, a main effect for Event Timing was found for temporal demand. In addition, no significant interaction effects were found with respect to overall workload, supporting hypotheses 10–13, but significant interaction effects were found between Control Method and Taskload with respect to mental workload, and Control Method and Event Timing with respect to physical workload. (see Table 4).

Table 4. ANOVA—Subjective Workload Significant Effects

Source	Sum of Squares	df	Mean Square	F	Sig.
Control Method					
Overall	**5.146**	**1**	**5.146**	**16.67**	**0.002**
Mental	9.557	1	9.5570	11.49	0.007
Physical	18.182	1	18.1820	15.39	0.003
Effort	4.545	1	4.5450	6.31	0.031
Frustration	2.909	1	2.9090	4.10	0.070
Event Timing					
Temporal	14.727	1	14.7270	14.34	0.004
Taskload					
Overall	**0.455**	**1**	**0.455**	**27.76**	**0.000**
Mental	4.102	1	4.1020	9.60	0.011
Physical	1.136	1	1.1360	6.10	0.033
Temporal	4.545	1	4.5450	13.16	0.005
Effort	2.909	1	2.9090	12.43	0.005
Frustration	2.909	1	2.9090	7.11	0.024
Control Method * Taskload					
Mental	2.557	1	2.5570	19.40	0.001
Control Method * Event Type					
Physical	1.636	1	1.6360	6.92	0.025

Plotting the mean response ratings for overall workload and each of the subscales by Control Method shows a consistent trend of users reporting lower perceived workload and higher performance when using eye tracking-based control (see Figure 24).

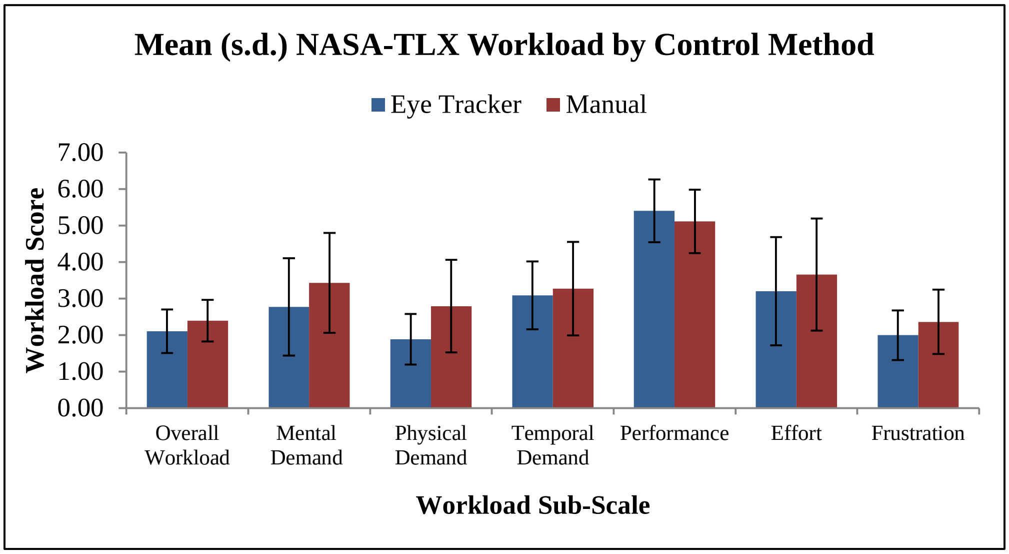

Figure 24. Mean Subjective Workload Scores by Control Method

A similar trend can be seen for the plot of mean workload response by Taskload condition in Figure 25, with users reporting lower perceived workload under low taskload conditions.

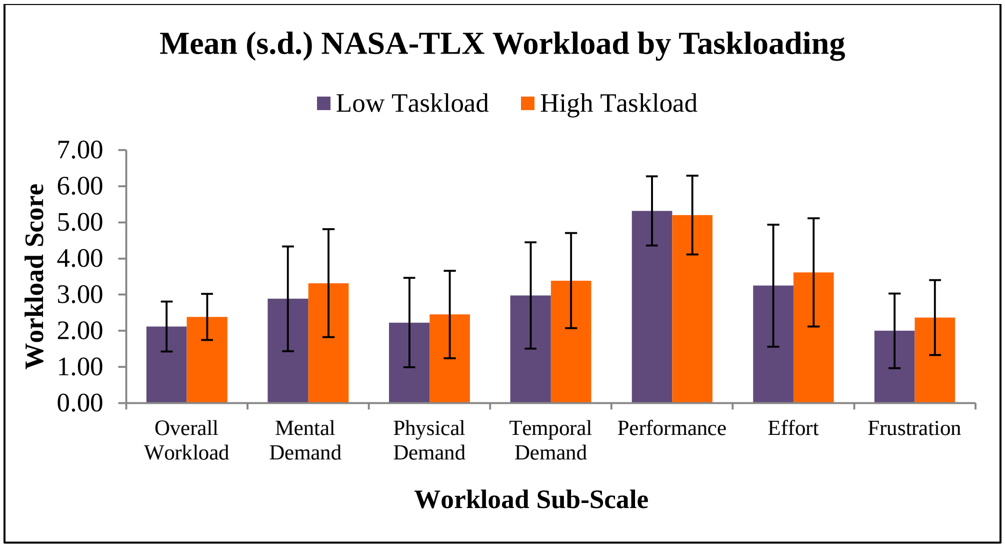

Figure 25. Mean Subjective Workload Scores by Taskload

For each of the Control Method main effects, a comparison using a paired t-test at alpha of 0.05 was conducted to identify significant differences in mean response for each of the subjective workload ratings. The comparison in Table 5 shows statistically significant differences between the mean subjective workloads for eye tracking and manual-based control, with eye tracking reporting lower perceived workload for each rating scale.

Table 5. Pair-wise Comparison of Mean Subjective Workload Response for Control Method

Source	Eye Tracking		Manual		Δ	df	t	Sig.
	Mean	S.D.	Mean	S.D				
Overall	**2.11**	**0.60**	**2.40**	**0.57**	**- 0.29**	**10**	**- 3.43**	**0.003**
Mental	2.77	1.33	3.43	1.37	- 0.66	10	- 3.39	0.003
Physical	1.89	0.69	2.80	1.27	- 0.91	10	- 3.92	0.001
Effort	3.20	1.48	3.66	1.53	- 0.45	10	- 2.51	0.015
Frustration	2.00	0.68	2.36	0.88	- 0.36	10	- 2.02	0.035

The comparison was repeated for the Taskload main effects (see Table 6). The comparison shows a statistically significant difference between the mean subjective workloads for low and high taskload conditions, with low taskload conditions having lower perceived workload for each rating scale.

Table 6. Pair-wise Comparison of Mean Subjective Workload Response for Taskload

Source	Eye Tracking		Manual		Δ	df	t	Sig.
	Mean	S.D.	Mean	S.D				
Overall	**2.12**	**0.58**	**2.39**	**0.57**	**- 0.27**	**10**	**-5.40**	**0.000**
Mental	2.89	1.36	3.32	1.30	-0.43	10	-3.10	0.006
Physical	2.23	0.89	2.45	1.02	-0.23	10	-2.50	0.017
Temporal	2.98	1.02	3.39	1.16	-0.41	10	-3.33	0.004
Effort	3.25	1.53	3.61	1.45	-0.36	10	-3.53	0.003
Frustration	2.00	0.72	2.36	0.80	-0.36	10	-2.67	0.012

Plotting temporal workload for event-driven and randomly timed threat occurrences shows the main effect of Event Timing (see Figure 26). A direct comparison of the mean temporal workload for event-driven (M = 3.61, SD = 1.29) and randomly timed threat task conditions

(M = 2.75, SD = 0.93) resulted in a significant difference, t (10) = 4.14, p = 0.001, with users perceiving randomly timed threat occurrences as having lower temporal demand. This result is consistent with user comments expressing a feeling of being rushed during event-driven task conditions.

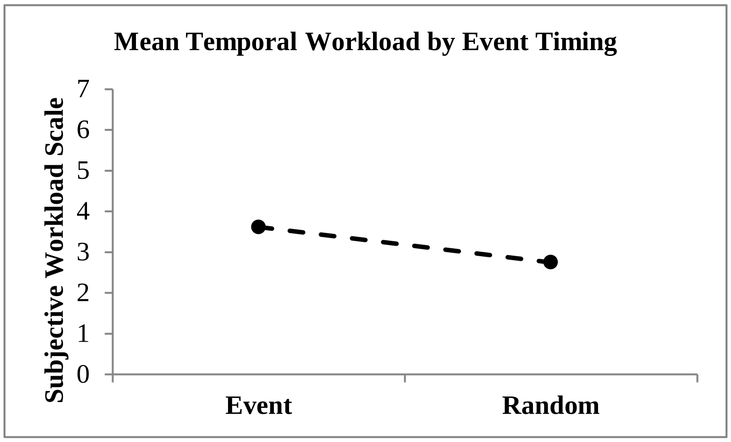

Figure 26. Mean Subjective Workload Score for Temporal Demand by Event Timing

Plotting mental workload by Control Method and Taskload in Figure 27 shows that the second order effect between the two factors is driven by the interaction between the manual control condition and taskload conditions. The slope of the line for manual-based control indicates an increasing trend in the perceived mental demand between the low (M = 3.05, SD = 1.46) and high (M = 3.82, SD = 1.40) taskload conditions with a significant difference in the mean ratings, t (10) = -5.49, p < 0.001. Comparatively, the slope between the low (M = 2.73, SD = 1.45) and high (M = 2.82, SD = 1.44) taskload conditions for eye tracking-based control is relatively flat, t (10) = -0.51, p = 0.31 with no significant difference in the mean ratings.

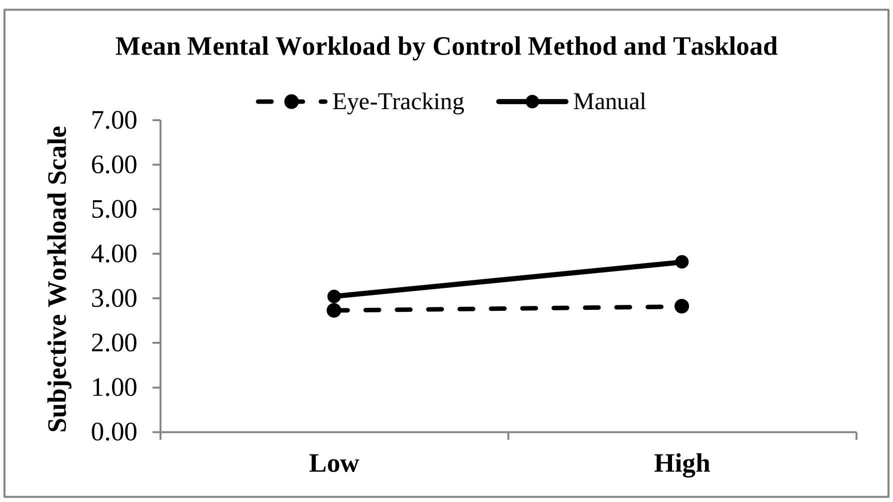

Figure 27. Mean Mental Workload by Control Method and Taskload

Plotting physical workload by Control Method and Event Timing in Figure 28 shows diverging trends in the second order effect between the two factors. The slope of the line for manual based control indicates a decreasing trend in the perceived physical workload between the event-driven (M = 2.95, SD = 1.46) and randomly timed threat task conditions (M = 2.64, SD = 1.33). No significant difference exists between the mean ratings, t (10) = 1.25, p = 0.12 for manual control. Conversely, the slope for eye-tracking control shows an increasing trend in perceived physical workload between the event-driven (M = 1.77, SD = 0.75) and randomly timed threat conditions (M = 2.00, SD = 0.87). Unlike manual control, a significant difference does exist between the mean physical workload ratings for eye tracking-based control during event and randomly timed threat conditions, t (10) = -2.19, p = 0.03.

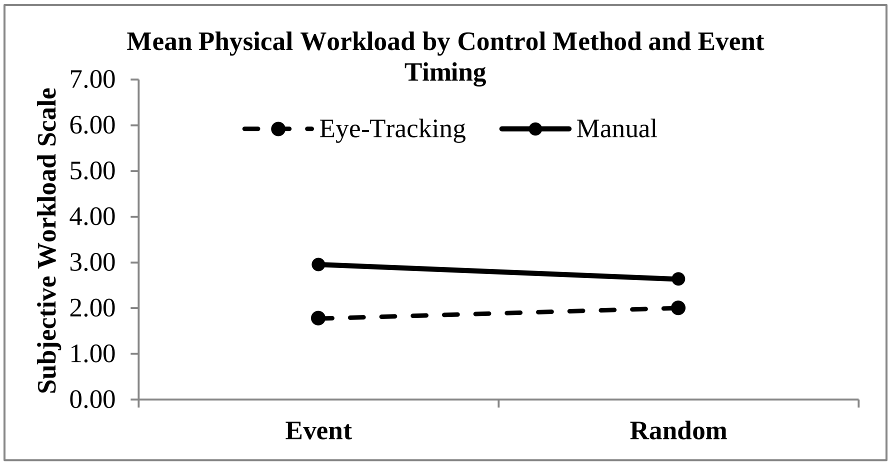

Figure 28. Mean Physical Workload by Control Method and Event Timing

6.0 CONCLUSION

Overall, eye tracking-based control was found to be a faster, less demanding method for switching between multiple displays compared to manual-based control for the given set of experimental conditions. Eye-tracking control, on average, was significantly faster by 0.71 sec per event, was equivalently accurate, and resulted in significantly lower subjective workload compared to manual-based control.

As expected, the time saved when using eye tracking-based control was a direct result of decreased manual inputs and increased speed with which users could visually switch between displays. In addition to the time saved, eye tracking-based control resulted in more consistent performance during each experimental condition; manual control having much greater variability with respect to event response time, particularly between event and randomly timed threat conditions. While the difference of less than a second may not be particularly impactful for a single event, extending the results of this study to tasks requiring users to switch hundreds or thousands of times between multiple displays shows an aggregate effect resulting in substantial time savings of minutes to hours.

Furthermore, the results of this study show that users perceived eye tracking-based control as less demanding, rating the associated overall workload for eye-tracking control lower than manual control. This result is consistent with the expectation that a control method using a user’s gaze would be an easy and intuitive method for switching control between multiple displays, since a user would naturally be looking at the display he or she intends to interact with or manipulate. Removing additional manual keystrokes or movements decreases physical demands as well as the physical complexity of the task that, in turn, decreases mental demands associated with controlling movement. A user no longer has to think of the correct manual responses to switch to a desired display but is able to simply look at the display automatically. This allows users to focus their cognitive processes to more important tasks related to processing information and decision making.

While a significant difference with respect to overall accuracy was not found, it is important to note that a nearly significant difference in quadrant selection accuracy was found between eye-tracking and manual-based control. As expected, users more accurately switched between quadrants when using eye tracking-based control compared to manual control, as users simply needed to look at the display of interest to correctly switch. During eye-tracking control, errors occurred only when a user looked away from the display or directly at the border between quadrants; conversely, during manual control, users routinely made keystroke errors switching to incorrect quadrants, requiring them to repeat and correct manual inputs. Anecdotally, while users recovered relatively quickly, recovering from manual mistakes was much slower than recovering from eye-tracking mistakes. The speed advantage provided by eye tracking-based control not only improves the speed of initial responses but for quicker recovery from errors compared to manual control.

Ultimately, this study shows that eye tracking-based control was a fast, accurate, and easy method for switching between multiple displays. As the amount and varieties of technology in command and control and combat system environments continues to increase, users will be faced with greater workload and demands when switching between greater numbers of displays. The results of this study show that incorporating eye tracking-based control can alleviate these demands, providing a fast, effective, and intuitive alternative to traditional manual control methods for switching between multiple displays.

REFERENCES

[1] C. H. Morimoto and M. R. M. Mimica, Eye Gaze Tracking Techniques for Interactive Applications, 2005.

[2] H. Aoki, J. P. Hansen, and K. Itoh, "Learning to Interact with a Computer by Gaze," *Behavior & Information Technology*, vol. 4, no. 27, p. 339—344, 2007.

[3] K. Rayner, "Eye Movements in Reading and Information Processing: 20 Years of Research," *Psychological Bulletin*, vol. 124, no. 3, pp. 373–422, 1998.

[4] M. Hayhoe and D. Ballard, "Eye Movements in Natural Behavior," *TRENDS in Cognitive Sciences*, vol. 9, no. 4, pp. 188–194, April 2005.

[5] S. Zhai, C. Moriomoto, and S. Ihde, "Manual and Gaze Input Cascade (MAGIC) Pointing," in *CHI '99 Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 1999, pp. 15–20.

[6] T. Shanker and M. Richtel. (2011, January) NYTimes.com. [Online]. http://www.nytimes.com/2011/01/17/technology/17brain.html?pagewanted=1&_r=4&

[7] A. Popola, P. Squire, and D. Liu, "The Effects of Eye Gaze-Based Control on Operator Performance while Monitoring Multiple Displays," in *2011 Human Systems Integration Symposium Proceedings American Society of Naval Engineers*, 2011, .

[8] S. G. Hart, "NASA-task load index (NASA-TLX): 20 Years Later," in *Proceedings of the 50th Annual Meeting of the Human Factors and Ergonomics Society (HFES),* San Fransisco, California, October 2006.

[9] B. E. John and D E. Kieras, "The GOMS Family of Analysis Techniques: Tools for Design and Evaluation. Human-Computer Interaction Institute," Technical Report CMU-HCII-94–106, 1994.

[10] D. E. Kieras, "Using the Keystroke-Level Model to Estimate Execution Times," Department of Psychology, University of Michigan, Ann Arbor, Michigan, Unpublished Report 2001.

[11] B. E. John and D. E. Kieras, "The GOMS Family of User Interface Analysis Techniques: Comparison and Contrast," *ACM Transactions on Computer-Human Interaction*, vol. 3, no. 4, pp. 320–351, 1996.

APPENDIX A: RECRUITMENT LETTER

Researchers in the W62 Human Systems Integration Branch are seeking volunteers for a study titled "Quick-Eye: The effects of eye gaze based control on operator performance in monitoring multiple displays." The experiment will be conducted in the Human Performance Lab located in building 1470, from Date TBD to Date TBD. The experiment is looking to understand the performance implications of using a newly developed interface control type utilizing eye tracking to gain control of individual monitors. The experiment is expected to last no more than one hour, and participation has no direct or indirect cost.

Quick-Eye System

If you would like to participate or have any questions concerning the study or participation requirements, please contact: Mr. Patrick Mead at patrick.mead1@navy.mil.

Thank you,
Patrick Mead
Applied Research Scientist and Engineer
Human Systems Integration Branch, W-62
NSWCDD Dahlgren, VA 22448
E-mail: patrick.mead1@navy.mil
Office: 540-653-5186

APPENDIX B: INFORMED CONSENT

1. Introduction:

You are being asked to voluntarily participate in a research study entitled *"**Examination of Human Performance Characteristics Using Eye Tracking and Manual Based Control Systems for Monitoring Multiple Displays**"*. Thank you for your willingness to participate in this experiment. Your participation will provide important information to us regarding the use of the eye tracking technology in monitoring scenarios. By volunteering, you are assisting us in obtaining valuable information.

2. Purpose of the study: Operators are increasingly responsible for monitoring multiple screen feeds from numerous devices and may be required to shift control quickly among these devices when confronted with complex, asymmetric threat situations. This switching is done manually, which can take seconds; however, a threat event can occur quickly, leaving the operator with only a brief window to respond. The goal is to evaluate eye-tracking technology and the use gaze information as an alternative to manual input for switching between multiple devices.

3. Procedures to be followed

You will experience eight conditions during two scenario types to study the effects of input method on task load, mental demand, workload, and accuracy. You will perform the entire experiment in the Human Performance Lab (HPL) in building 1470.

4. Discomforts and Risks:

As a result of participating in this study, participants will be exposed to no additional risk beyond the normal risk present at their workplace.

5. Benefits: The benefits to society and you are described below:

(a) Benefits to You: You will receive no benefits directly; however, you will be participating in a continued study to investigate the eye tracking technology in a way that has not been done before.

(b) Potential Benefits to Society: The sponsor (NISE) will get a proof of concept, possible patents, research papers. This study could lead to future larger scale studies and can serve as a baseline to pave the way. The eye tracking technology used in this study could potentially provide new ways to decrease operator workload and increase the ability to detect targets faster and with more precision.

6. Duration/Time of the Procedures and Study:

Each participant will need no more than one hour to complete this study.

7. Alternative Procedures that could be utilized:

N/A

8. Statement of Confidentiality:

Every reasonable effort will be made to keep your responses and identity confidential. The U.S. Navy may keep, preserve, use in any manner, and dispose of the findings of this evaluation, including your input or opinions. Information collected during this study is subject to the Privacy Act of 1974, which is described below:

The Privacy Act of 1974, 5 U.S.C. § 552a, establishes a code of fair information practices that governs the collection, maintenance, use, and dissemination of personally identifiable information about individuals that is maintained in systems of records by federal agencies. A system of records is a group of records under the control of an agency from which information is retrieved by the name of the individual or by some identifier assigned to the individual. The Privacy Act requires that agencies give the public notice of their systems of records by publication in the Federal Register. The Privacy Act prohibits the disclosure of information from a system of records absent the written consent of the subject individual, unless the disclosure is pursuant to one of twelve statutory exceptions. The Act also provides individuals with a means by which to seek access to and amendment of their records, and sets forth various agency recordkeeping requirements.

The tenets of the Privacy Act, SECNAVINST 5211.5E, will be followed. Only the Department of the Navy, Department of Defense, and other U.S. Government agencies will use the information gained from the studies described in the protocol, provided the use is compatible with the purpose for which the information was collected. Anyone needing to use this data for purposes other than what is described on this informed consent form will need to obtain authorization from each participant to use the data in the proposed manner. Any reports or publications containing data resulting from studies will not identify you by name or initials unless your express permission is obtained. The Commander of the Naval Surface Warfare Center, Dahlgren Division may grant approval for use of the information to non-Government agencies or individuals.

The objective and subjective information gathered in this study is considered Personally Identifiable Information (PII), and will be handled and stored in accordance with NSWCDD Instruction 5211.1C (Privacy Act Program). Hardcopy data will be stored in a locked container in Building 1470 for a period of three years; informed consent and collected data sheets will be physically separated. Electronic data will be password protected.

By participating in this study, you agree to maintain in strict confidence all information disclosed to you, and you agree not to use directly or indirectly for your own benefit, or the benefit of other third parties, any information presented at the time of this study.

9. Right to Ask Questions

You have a right to ask questions at any time before, during, or after the test. Please contact the Principal Investigator, one of the Associate Investigators, the medical monitor, or the Institutional Review Board (IRB) chair at any time with questions, complaints, or concerns about the research. They are:

Principal Investigator: Patrick Mead
Naval Surface Warfare Center –
Dahlgren Division
ATTN: Code W62
18444 Frontage Road, Suite 327
Dahlgren, VA 22448-5161
(540) 653-5186
patrick.mead1@navy.mil

IRB Chair: Meredith Bondurant
Naval Surface Warfare Center –
Dahlgren Division
ATTN: Code Z20
4045 Higley Road Suite 344
Dahlgren, VA 22448-5162
(540) 653-9201
meredith.bondurant@navy.mil

10. Payment for Participation: There is no cost to you for participating in this study. Your participation in this study is voluntary, refusing to participate will involve no penalty, and you may discontinue your participation at any time without consequence. The principal investigator reserves the right to stop and end participation at any point if it is in the best interest of the participant.

11. Cost of Participating: There is no cost directly or indirectly for participation in this study.

12. Voluntary Participation: Your participation in this study is voluntary. You may withdraw from this study at any time by notifying any of the investigators. You may decline to answer any or all questions. Refusal to take part in, or withdrawing from, this study will involve no penalty or loss of benefits you would otherwise receive.

13. Injury Clause: There is no additional risk anticipated to participate in this study, however, if you feel that you have incurred a research related injury, contact the principal investigator.

14. Participation Requirements: We are looking for civilian and active duty personnel stationed at the Naval Surface Warfare Center Dahlgren with normal or corrected to normal vision. Please remember, you cannot fail any part of this study, and there is no right or wrong answer. The purpose of this study is to evaluate eye gaze based control. We are not in any way evaluating your abilities.

If you agree to take part in this research study and the information outlined above, please sign your name and indicate the date below. By signing below, you are also certifying that you have been informed of the information above and that your participation in this study is voluntary. You will be given a copy of this signed and dated consent form for your records.

Participant's Name	**Participant's signature**	**Date**
Investigator's Name	**Investigator's signature**	**Date**

(THIS PAGE INTENTIONALLY LEFT BLANK)

APPENDIX C: DEMOGRAPHICS QUESTIONNAIRE

Demographics Questionnaire (Experimenter Use Only):

Participant Number: ________________

Glasses: Yes_____ No_____

Age: ______

Gender: ______

APPENDIX D: NASA-TLX SUBJECTIVE WORKLOAD QUESTIONNAIRE

Condition 1—Mode: _________

Mental Demand: How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?

1 2 3 4 5 6 7 8

Low ---High

Physical Demand: How physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?

1 2 3 4 5 6 7 8

Low ---High

Temporal Demand: How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?

1 2 3 4 5 6 7 8

Low ---High

Performance: How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?

1 2 3 4 5 6 7 8

Good ---Poor

Effort: How hard did you have to work (mentally and physically) to accomplish your level of performance?

1 2 3 4 5 6 7 8

Low ---High

Frustration: How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed, and complacent did you feel during the task?

1 2 3 4 5 6 7 8

Low ---High

APPENDIX E: DATA TABLES

Experimental Evaluation Raw Data per Measure

Table 7. Aggregated Raw Data per Measure

Avg. Event Response Time (s)	Ey-Ev-Hi	Ey-Ev-Lw	Ey-Rd-Hi	Ey-Rd-Lw	Mn-Ev-Hi	Mn-Ev-Lw	Mn-Rd-Hi	Mn-Rd-Lw
1	0.77	0.89	0.74	0.82	1.49	1.94	1.31	1.40
2	0.74	0.74	0.74	0.71	1.12	1.54	1.22	1.23
3	1.01	1.10	0.95	1.08	2.10	2.29	2.12	1.90
4	0.89	0.89	1.06	0.89	1.23	1.72	1.82	1.09
5	0.82	0.89	0.84	0.77	1.79	1.47	1.77	1.46
6	0.94	0.97	1.05	0.94	1.78	2.25	1.68	1.36
7	0.83	1.06	0.73	0.85	1.46	1.66	1.16	1.35
8	0.77	0.92	1.05	0.89	2.22	1.63	1.40	1.90
9	0.73	0.63	0.81	0.80	1.25	1.45	1.08	1.12
10	0.72	0.74	0.72	0.72	1.13	1.05	0.91	1.02
11	1.22	1.10	0.97	1.07	2.23	2.13	2.35	2.26
Avg. Switch Time (s)	**Ey-Ev-Hi**	**Ey-Ev-Lw**	**Ey-Rd-Hi**	**Ey-Rd-Lw**	**Mn-Ev-Hi**	**Mn-Ev-Lw**	**Mn-Rd-Hi**	**Mn-Rd-Lw**
1	0.20	0.22	0.16	0.21	0.88	1.17	0.80	0.95
2	0.21	0.21	0.23	0.24	0.82	1.11	0.92	0.91
3	0.25	0.26	0.19	0.19	1.26	1.53	1.25	1.25
4	0.19	0.23	0.07	0.20	0.78	1.13	1.12	0.67
5	0.21	0.21	0.20	0.21	1.34	1.12	1.35	1.13
6	0.27	0.25	0.23	0.24	1.27	1.42	1.23	1.11
7	0.25	0.21	0.18	0.20	0.89	1.00	0.82	0.99
8	0.25	0.25	0.25	0.23	1.30	1.03	0.90	1.23
9	0.09	0.21	0.19	0.17	0.72	0.84	0.70	0.74
10	0.21	0.21	0.17	0.21	0.67	0.61	0.67	0.71
11	0.26	0.25	0.24	0.21	1.44	1.50	1.52	1.50
Avg. Target Response Time (s)	**Ey-Ev-Hi**	**Ey-Ev-Lw**	**Ey-Rd-Hi**	**Ey-Rd-Lw**	**Mn-Ev-Hi**	**Mn-Ev-Lw**	**Mn-Rd-Hi**	**Mn-Rd-Lw**
1	0.51	0.62	0.49	0.54	0.63	0.85	0.54	0.43
2	0.49	0.49	0.51	0.49	0.29	0.40	0.26	0.29
3	0.75	0.83	0.69	0.80	0.90	0.86	0.95	0.77
4	0.55	0.54	0.48	0.55	0.49	0.67	0.77	0.46
5	0.53	0.64	0.54	0.53	0.30	0.34	0.37	0.27
6	0.65	0.70	0.79	0.66	0.58	0.90	0.52	0.36
7	0.54	0.67	0.53	0.59	0.51	0.63	0.41	0.47
8	0.53	0.68	0.60	0.61	0.93	0.64	0.56	0.78
9	0.42	0.40	0.55	0.47	0.51	0.58	0.38	0.40
10	0.47	0.48	0.49	0.49	0.50	0.42	0.31	0.37
11	0.86	0.83	0.74	0.80	0.77	0.63	0.80	0.71

a. Table 7 (cont'd)

Quadrant Error Rate (%)	Ey-Ev-Hi	Ey-Ev-Lw	Ey-Rd-Hi	Ey-Rd-Lw	Mn-Ev-Hi	Mn-Ev-Lw	Mn-Rd-Hi	Mn-Rd-Lw
1	0.00%	0.00%	0.00%	0.00%	2.00%	2.00%	2.00%	10.00%
2	1.00%	0.00%	0.00%	0.00%	0.00%	2.00%	3.00%	2.00%
3	0.00%	2.00%	0.00%	2.00%	2.00%	0.00%	3.00%	0.00%
4	3.00%	2.00%	7.00%	0.00%	1.00%	0.00%	2.00%	0.00%
5	5.00%	2.00%	2.00%	2.00%	9.00%	0.00%	1.00%	0.00%
6	0.00%	0.00%	0.00%	0.00%	3.00%	2.00%	7.00%	2.00%
7	0.00%	2.00%	0.00%	2.00%	5.00%	4.00%	1.00%	0.00%
8	0.00%	0.00%	8.00%	0.00%	2.00%	4.00%	3.00%	2.00%
9	3.00%	0.00%	2.00%	8.00%	5.00%	2.00%	5.00%	6.00%
10	1.00%	0.00%	0.00%	0.00%	0.00%	4.00%	0.00%	2.00%
11	6.00%	2.00%	0.00%	0.00%	2.00%	0.00%	0.00%	0.00%
Value Error Rate (%)	**Ey-Ev-Hi**	**Ey-Ev-Lw**	**Ey-Rd-Hi**	**Ey-Rd-Lw**	**Mn-Ev-Hi**	**Mn-Ev-Lw**	**Mn-Rd-Hi**	**Mn-Rd-Lw**
1	12.00%	8.00%	10.00%	12.00%	5.00%	2.00%	7.00%	8.00%
2	6.00%	6.00%	4.00%	2.00%	2.00%	2.00%	4.00%	2.00%
3	2.00%	2.00%	7.00%	8.00%	4.00%	2.00%	4.00%	4.00%
4	12.00%	6.00%	18.00%	8.00%	3.00%	4.00%	5.00%	10.00%
5	7.00%	0.00%	6.00%	8.00%	5.00%	2.00%	9.00%	10.00%
6	0.00%	2.00%	2.00%	4.00%	1.00%	2.00%	0.00%	0.00%
7	6.00%	6.00%	1.00%	2.00%	8.00%	12.00%	8.00%	2.00%
8	1.00%	0.00%	6.00%	4.00%	7.00%	2.00%	1.00%	2.00%
9	1.00%	4.00%	1.00%	2.00%	4.00%	12.00%	7.00%	8.00%
10	3.00%	4.00%	2.00%	2.00%	4.00%	4.00%	0.00%	6.00%
11	0.00%	0.00%	1.00%	4.00%	0.00%	0.00%	3.00%	2.00%
Overall Workload	**Ey-Ev-Hi**	**Ey-Ev-Lw**	**Ey-Rd-Hi**	**Ey-Rd-Lw**	**Mn-Ev-Hi**	**Mn-Ev-Lw**	**Mn-Rd-Hi**	**Mn-Rd-Lw**
1	2.71	2.57	2.29	1.57	2.57	2.86	2.43	2.14
2	3.57	3.57	2.57	2.00	3.43	3.00	3.29	2.43
3	3.00	3.43	3.00	3.14	3.43	2.57	2.86	3.00
4	2.29	2.71	3.14	1.86	2.71	2.86	3.14	2.29
5	1.71	1.57	1.71	1.29	2.00	1.86	1.71	1.71
6	1.29	1.43	1.00	1.00	1.43	1.00	1.86	1.14
7	2.43	2.71	2.00	1.57	2.71	2.71	2.14	2.43
8	1.53	1.10	2.25	1.71	2.38	1.33	1.48	1.62
9	2.43	1.86	2.14	1.71	2.86	2.71	3.00	2.57
10	2.16	2.00	2.49	1.87	3.43	3.29	2.43	2.29
11	1.73	1.21	1.60	1.83	2.43	1.56	2.22	2.10

Table 7 (cont'd)

Mental Workload	Ey-Ev-Hi	Ey-Ev-Lw	Ey-Rd-Hi	Ey-Rd-Lw	Mn-Ev-Hi	Mn-Ev-Lw	Mn-Rd-Hi	Mn-Rd-Lw
1	2	4	3	2	4	4	4	3
2	5	4	4	3	5	5	5	3
3	5	5	5	6	5	4	5	5
4	2	4	5	4	4	4	5	3
5	1	1	1	1	2	1	2	1
6	1	1	1	1	1	1	3	1
7	2	3	2	2	3	4	3	3
8	2	1	3	2	3	2	3	2
9	3	3	3	3	5	5	6	4
10	3	4	5	3	6	4	5	5
11	2	1	2	2	3	1	2	2
Physical Workload	**Ey-Ev-Hi**	**Ey-Ev-Lw**	**Ey-Rd-Hi**	**Ey-Rd-Lw**	**Mn-Ev-Hi**	**Mn-Ev-Lw**	**Mn-Rd-Hi**	**Mn-Rd-Lw**
1	2	1	2	1	4	3	4	3
2	3	3	3	3	5	5	5	3
3	3	2	3	4	3	4	3	5
4	2	1	2	1	3	3	1	2
5	1	1	1	1	1	1	1	1
6	1	1	1	1	1	1	1	1
7	2	1	3	1	3	2	2	3
8	2	1	2	2	2	1	2	2
9	2	2	2	2	4	4	2	2
10	3	2	3	2	4	6	4	5
11	2	1	2	2	2	3	3	3
Temporal Workload	**Ey-Ev-Hi**	**Ey-Ev-Lw**	**Ey-Rd-Hi**	**Ey-Rd-Lw**	**Mn-Ev-Hi**	**Mn-Ev-Lw**	**Mn-Rd-Hi**	**Mn-Rd-Lw**
1	4	5	2	1	3	4	3	3
2	5	4	4	3	5	6	5	3
3	4	5	4	3	3	6	3	5
4	3	3	4	1	6	5	4	2
5	2	2	2	2	2	2	2	1
6	2	3	1	1	1	2	2	1
7	3	5	2	2	2	3	2	2
8	3	2	3	2	2	3	2	3
9	5	4	4	2	3	3	3	4
10	6	5	5	3	7	6	4	5
11	3	2	2	3	2	3	3	3

b. Table 7 (cont'd)

Performance	**Ey-Ev-Hi**	**Ey-Ev-Lw**	**Ey-Rd-Hi**	**Ey-Rd-Lw**	**Mn-Ev-Hi**	**Mn-Ev-Lw**	**Mn-Rd-Hi**	**Mn-Rd-Lw**
1	4	6	4	4	4	4	4	4
2	3	2	4	5	5	4	4	4
3	6	5	5	4	6	5	5	6
4	6	6	5	6	6	6	6	6
5	6	6	5	6	6	5	5	4
6	7	6	7	6	6	6	5	6
7	5	5	5	6	4	5	6	5
8	6	6	4	6	6	5	6	5
9	5	6	6	5	4	3	3	4
10	7	6	7	6	6	6	7	6
11	6	6	6	5	6	5	5	6
Effort	**Ey-Ev-Hi**	**Ey-Ev-Lw**	**Ey-Rd-Hi**	**Ey-Rd-Lw**	**Mn-Ev-Hi**	**Mn-Ev-Lw**	**Mn-Rd-Hi**	**Mn-Rd-Lw**
1	4	3	4	1	5	3	3	3
2	5	5	4	3	5	5	5	4
3	6	6	6	6	6	6	5	6
4	4	6	5	4	4	4	6	5
5	1	1	1	1	1	1	1	1
6	2	2	1	1	1	2	3	1
7	4	4	4	2	4	5	4	4
8	2	2	3	3	2	3	2	2
9	4	3	4	3	5	4	4	4
10	4	3	4	3	6	6	5	4
11	2	1	2	2	2	3	3	3
Frustration	**Ey-Ev-Hi**	**Ey-Ev-Lw**	**Ey-Rd-Hi**	**Ey-Rd-Lw**	**Mn-Ev-Hi**	**Mn-Ev-Lw**	**Mn-Rd-Hi**	**Mn-Rd-Lw**
1	4	3	2	2	3	2	2	2
2	4	4	2	2	3	3	3	3
3	2	1	2	2	2	2	3	2
4	1	1	2	1	2	2	3	1
5	1	1	1	1	1	1	1	1
6	1	1	1	1	1	1	1	1
7	3	3	2	1	4	3	2	3
8	2	1	3	3	1	4	1	1
9	3	2	3	2	3	4	4	3
10	2	1	3	3	5	5	3	1
11	2	2	2	2	2	3	3	3

Mean, Standard Deviation, and Confidence Interval Data per Measure

Table 8. Mean, Standard Deviation, and Confidence Interval (Control Method)

Measure	**Control Method**	*M*	*SD*	**95% Confidence Interval** *LB*	*UB*
Avg. Event Response Time (s)	Eye-tracking	0.88	0.04	0.79	0.96
	Manual	1.59	0.11	1.34	1.84
Avg. Switch Time (s)	Eye-tracking	0.21	0.01	0.19	0.23
	Manual	1.05	0.08	0.88	1.22
Avg. Target Response Time (s)	Eye-tracking	0.59	0.04	0.52	0.67
	Manual	0.56	0.05	0.44	0.68
Quadrant Error Rate	Eye-tracking	1.00%	0.00%	1.00%	2.00%
	Manual	2.00%	0.00%	1.00%	3.00%
Value Error Rate	Eye-tracking	5.00%	1.00%	2.00%	7.00%
	Manual	4.00%	1.00%	3.00%	6.00%
Overall Workload	Eye-tracking	2.42	0.26	1.85	2.99
	Manual	2.90	0.30	2.23	3.58
Mental Workload	Eye-tracking	2.77	0.40	1.88	3.67
	Manual	3.43	0.41	2.52	4.35
Physical Workload	Eye-tracking	1.89	0.21	1.42	2.35
	Manual	2.80	0.38	1.94	3.65
Temporal Workload	Eye-tracking	3.05	0.31	2.37	3.73
	Manual	3.27	0.39	2.41	4.13
Performance	Eye-tracking	5.41	0.26	4.83	5.99
	Manual	5.11	0.26	4.53	5.70
Effort	Eye-tracking	3.21	0.45	2.21	4.20
	Manual	3.66	0.46	2.63	4.69
Frustration	Eye-tracking	2.00	0.21	1.54	2.46
	Manual	2.36	0.27	1.77	2.96

Table 9. Mean, Standard Deviation, and Confidence Interval (Event Timing)

Measure	**Event Timing**	*M*	*SD*	**95% Confidence Interval** *LB*	*UB*
Avg. Event Response Time (s)	Event	1.28	0.07	1.12	1.45
	Random	1.18	0.08	1.02	1.35
Avg. Switch Time (s)	Event	0.65	0.04	0.56	0.75
	Random	0.61	0.04	0.52	0.70
Avg. Target Response Time (s)	Event	0.60	0.04	0.51	0.70
	Random	0.55	0.04	0.46	0.64
Quadrant Error Rate	Event	2.00%	0.00%	1.00%	3.00%
	Random	2.00%	1.00%	1.00%	3.00%
Value Error Rate	Event	4.00%	1.00%	2.00%	6.00%
	Random	5.00%	1.00%	3.00%	7.00%
Overall Workload	Event	2.76	0.31	2.06	3.46
	Random	2.56	0.24	2.01	3.10
Mental Workload	Event	3.07	0.41	2.15	3.99
	Random	3.14	0.39	2.26	4.01
Physical Workload	Event	2.36	0.30	1.69	3.04
	Random	2.32	0.29	1.67	2.97
Temporal Workload	Event	3.57	0.41	2.65	4.49
	Random	2.75	0.28	2.13	3.37
Performance	Event	5.32	0.27	4.73	5.91
	Random	5.21	0.23	4.70	5.71
Effort	Event	3.57	0.48	2.51	4.63
	Random	3.30	0.43	2.34	4.25
Frustration	Event	2.32	0.28	1.70	2.94
	Random	2.05	0.19	1.63	2.46

Table 10. Mean, Standard Deviation, and Confidence Interval (Taskload)

Measure	Taskload			95% Confidence Interval	
		M	*SD*	*LB*	*UB*
Avg. Event Response Time (s)	Low	1.24	0.07	1.09	1.40
	High	1.22	0.08	1.05	1.40
Avg. Switch Time (s)	Low	0.65	0.04	0.56	0.73
	High	0.62	0.05	0.52	0.72
Avg. Target Response Time (s)	Low	0.58	0.04	0.49	0.67
	High	0.57	0.04	0.47	0.67
Quadrant Error Rate	Low	2.00%	0.00%	1.00%	2.00%
	High	2.00%	0.00%	1.00%	3.00%
Value Error Rate	Low	4.00%	1.00%	3.00%	6.00%
	High	5.00%	1.00%	3.00%	6.00%
Overall Workload	Low	2.50	0.27	1.90	3.10
	High	2.82	0.28	2.20	3.44
Mental Workload	Low	2.89	0.41	1.98	3.80
	High	3.32	0.39	2.44	4.19
Physical Workload	Low	2.23	0.27	1.63	2.83
	High	2.46	0.31	1.77	3.14
Temporal Workload	Low	2.93	0.33	2.20	3.67
	High	3.39	0.35	2.60	4.17
Performance	Low	5.32	0.21	4.86	5.78
	High	5.21	0.28	4.60	5.82
Effort	Low	3.25	0.46	2.22	4.28
	High	3.61	0.44	2.64	4.59
Frustration	Low	2.00	0.22	1.51	2.49
	High	2.36	0.24	1.83	2.90

Table 11. Mean, Standard Deviation, and Confidence Interval (Control Method x Event Timing)

Measure	Control Method	Event Timing			95% Confidence Interval	
			M	*SD*	*LB*	*UB*
Avg. Event Response Time (s)	Eye-tracking	Event	0.88	0.04	0.78	0.98
		Random	0.87	0.04	0.79	0.95
	Manual	Event	1.68	0.11	1.43	1.92
		Random	1.50	0.12	1.23	1.76
Avg. Switch Time (s)	Eye-tracking	Event	0.22	0.01	0.20	0.24
		Random	0.20	0.01	0.18	0.22
	Manual	Event	1.08	0.08	0.91	1.26
		Random	1.02	0.08	0.85	1.19
Avg. Target Response Time (s)	Eye-tracking	Event	0.60	0.04	0.51	0.69
		Random	0.59	0.03	0.52	0.66
	Manual	Event	0.61	0.06	0.48	0.73
		Random	0.51	0.06	0.38	0.64
Quadrant Error Rate	Eye-tracking	Event	1.00%	0.00%	0.00%	2.00%
		Random	2.00%	1.00%	0.00%	3.00%
	Manual	Event	2.00%	0.00%	1.00%	3.00%
		Random	2.00%	1.00%	1.00%	4.00%
Value Error Rate	Eye-tracking	Event	4.00%	1.00%	2.00%	6.00%
		Random	5.00%	1.00%	3.00%	8.00%
	Manual	Event	4.00%	1.00%	2.00%	6.00%
		Random	5.00%	1.00%	3.00%	7.00%
Overall Workload	Eye-tracking	Event	2.49	0.30	1.83	3.14
		Random	2.35	0.25	1.80	2.90
	Manual	Event	3.04	0.35	2.25	3.83
		Random	2.76	0.26	2.19	3.34
Mental Workload	Eye-tracking	Event	2.68	0.41	1.78	3.59
		Random	2.86	0.43	1.91	3.82
	Manual	Event	3.46	0.44	2.46	4.45
		Random	3.41	0.39	2.54	4.28
Physical Workload	Eye-tracking	Event	1.77	0.20	1.34	2.21
		Random	2.00	0.23	1.48	2.52
	Manual	Event	2.96	0.43	2.00	3.91
		Random	2.64	0.38	1.80	3.47
Temporal Workload	Eye-tracking	Event	3.55	0.39	2.68	4.41
		Random	2.55	0.27	1.94	3.16
	Manual	Event	3.59	0.50	2.48	4.70
		Random	2.96	0.31	2.28	3.63
Performance	Eye-tracking	Event	5.50	0.34	4.75	6.25
		Random	5.32	0.24	4.79	5.84
	Manual	Event	5.14	0.26	4.55	5.72
		Random	5.09	0.29	4.46	5.73
Effort	Eye-tracking	Event	3.36	0.48	2.29	4.44
		Random	3.05	0.44	2.07	4.02
	Manual	Event	3.77	0.51	2.64	4.91
		Random	3.55	0.44	2.56	4.54
Frustration	Eye-tracking	Event	2.05	0.32	1.33	2.76
		Random	1.96	0.21	1.49	2.42
	Manual	Event	2.59	0.35	1.81	3.37
		Random	2.14	0.26	1.55	2.72

Table 12. Mean, Standard Deviation, and Confidence Interval (Control Method x Taskload)

Measure	Control Method	Taskload	*M*	*SD*	95% Confidence Interval *LB*	95% Confidence Interval *UB*
Avg. Event Response Time (s)	Eye-tracking	Low	0.89	0.04	0.80	0.97
		High	0.87	0.04	0.78	0.95
	Manual	Low	1.60	0.11	1.37	1.83
		High	1.57	0.12	1.30	1.85
Avg. Switch Time (s)	Eye-tracking	Low	0.22	0.01	0.21	0.23
		High	0.21	0.01	0.18	0.23
	Manual	Low	1.08	0.08	0.91	1.24
		High	1.03	0.08	0.85	1.21
Avg. Target Response Time (s)	Eye-tracking	Low	0.61	0.04	0.53	0.69
		High	0.58	0.03	0.50	0.65
	Manual	Low	0.56	0.05	0.45	0.66
		High	0.56	0.06	0.42	0.69
Quadrant Error Rate	Eye-tracking	Low	1.00%	0.00%	0.00%	2.00%
		High	2.00%	1.00%	0.00%	3.00%
	Manual	Low	2.00%	1.00%	1.00%	3.00%
		High	3.00%	1.00%	2.00%	4.00%
Value Error Rate	Eye-tracking	Low	4.00%	1.00%	3.00%	6.00%
		High	5.00%	1.00%	2.00%	8.00%
	Manual	Low	5.00%	1.00%	3.00%	6.00%
		High	4.00%	1.00%	3.00%	6.00%
Overall Workload	Eye-tracking	Low	2.25	0.25	1.70	2.80
		High	2.58	0.27	1.98	3.18
	Manual	Low	2.74	0.31	2.05	3.44
		High	3.06	0.30	2.39	3.73
Mental Workload	Eye-tracking	Low	2.73	0.42	1.79	3.67
		High	2.82	0.40	1.93	3.71
	Manual	Low	3.05	0.42	2.10	3.99
		High	3.82	0.41	2.90	4.74
Physical Workload	Eye-tracking	Low	1.64	0.23	1.11	2.16
		High	2.14	0.21	1.66	2.61
	Manual	Low	2.82	0.35	2.03	3.60
		High	2.77	0.43	1.82	3.73
Temporal Workload	Eye-tracking	Low	2.77	0.29	2.13	3.42
		High	3.32	0.37	2.51	4.13
	Manual	Low	3.09	0.43	2.14	4.04
		High	3.46	0.37	2.63	4.28
Performance	Eye-tracking	Low	5.41	0.24	4.87	5.95
		High	5.41	0.32	4.69	6.13
	Manual	Low	5.23	0.26	4.66	5.80
		High	5.00	0.30	4.33	5.67
Effort	Eye-tracking	Low	2.96	0.46	1.92	3.99
		High	3.46	0.46	2.44	4.47
	Manual	Low	3.55	0.50	2.43	4.66
		High	3.77	0.44	2.78	4.76
Frustration	Eye-tracking	Low	1.82	0.19	1.39	2.25
		High	2.18	0.23	1.68	2.69
	Manual	Low	2.18	0.28	1.56	2.81
		High	2.55	0.30	1.88	3.21

Table 13. Mean, Standard Deviation, and Confidence Interval (Event Timing x Taskload)

Measure	Event Timing	Taskload	*M*	*SD*	95% Confidence Interval *LB*	95% Confidence Interval *UB*
Avg. Event Response Time (s)	Event	Low	1.32	0.08	1.15	1.49
		High	1.24	0.08	1.06	1.42
	Random	Low	1.17	0.08	1.00	1.33
		High	1.20	0.08	1.02	1.39
Avg. Switch Time (s)	Event	Low	0.68	0.04	0.58	0.78
		High	0.63	0.05	0.52	0.73
	Random	Low	0.61	0.04	0.53	0.70
		High	0.61	0.05	0.51	0.71
Avg. Target Response Time (s)	Event	Low	0.63	0.04	0.53	0.72
		High	0.58	0.05	0.48	0.68
	Random	Low	0.54	0.04	0.44	0.63
		High	0.56	0.04	0.46	0.66
Quadrant Error Rate	Event	Low	1.00%	0.00%	1.00%	2.00%
		High	2.00%	1.00%	1.00%	4.00%
	Random	Low	2.00%	1.00%	0.00%	3.00%
		High	2.00%	1.00%	1.00%	3.00%
Value Error Rate	Event	Low	4.00%	1.00%	2.00%	6.00%
		High	4.00%	1.00%	2.00%	6.00%
	Random	Low	5.00%	1.00%	3.00%	7.00%
		High	5.00%	1.00%	3.00%	7.00%
Overall Workload	Event	Low	2.63	0.33	1.90	3.36
		High	2.90	0.31	2.20	3.59
	Random	Low	2.36	0.25	1.81	2.92
		High	2.75	0.25	2.18	3.32
Mental Workload	Event	Low	3.00	0.46	1.98	4.02
		High	3.14	0.41	2.23	4.04
	Random	Low	2.77	0.40	1.88	3.67
		High	3.50	0.41	2.59	4.41
Physical Workload	Event	Low	2.18	0.28	1.56	2.81
		High	2.55	0.35	1.77	3.32
	Random	Low	2.27	0.32	1.56	2.98
		High	2.36	0.30	1.71	3.02
Temporal Workload	Event	Low	3.36	0.44	2.38	4.35
		High	3.77	0.40	2.88	4.67
	Random	Low	2.50	0.30	1.83	3.17
		High	3.00	0.32	2.30	3.71
Performance	Event	Low	5.41	0.25	4.85	5.97
		High	5.23	0.30	4.55	5.91
	Random	Low	5.23	0.21	4.77	5.69
		High	5.18	0.26	4.60	5.77
Effort	Event	Low	3.50	0.51	2.36	4.64
		High	3.64	0.45	2.63	4.65
	Random	Low	3.00	0.44	2.02	3.99
		High	3.59	0.44	2.62	4.56
Frustration	Event	Low	2.14	0.30	1.46	2.81
		High	2.50	0.29	1.85	3.16
	Random	Low	1.86	0.18	1.46	2.26
		High	2.23	0.23	1.72	2.73

Table 14. Mean, Standard Deviation, and Confidence Interval (Control Method x Event Timing x Taskload)

Measure	Control Method	Event Timing	Taskload	*M*	*SD*	95% Confidence Interval *LB*	95% Confidence Interval *UB*
Avg. Event Response Time (s)	Eye-tracking	Event	Low	0.90	0.05	0.80	1.01
			High	0.86	0.05	0.76	0.96
		Random	Low	0.87	0.04	0.78	0.95
			High	0.88	0.04	0.78	0.97
	Manual	Event	Low	1.74	0.12	1.48	2.00
			High	1.62	0.13	1.33	1.91
		Random	Low	1.46	0.12	1.20	1.73
			High	1.53	0.14	1.22	1.84
Avg. Switch Time (s)	Eye-tracking	Event	Low	0.23	0.01	0.21	0.24
			High	0.22	0.02	0.18	0.25
		Random	Low	0.21	0.01	0.20	0.22
			High	0.19	0.00	0.16	0.23
	Manual	Event	Low	1.13	0.08	0.95	1.32
			High	1.03	0.09	0.84	1.23
		Random	Low	1.02	0.08	0.84	1.19
			High	1.03	0.09	0.84	1.22
Avg. Target Response Time (s)	Eye-tracking	Event	Low	0.63	0.04	0.53	0.72
			High	0.57	0.04	0.49	0.66
		Random	Low	0.59	0.04	0.52	0.67
			High	0.58	0.03	0.51	0.66
	Manual	Event	Low	0.63	0.06	0.50	0.76
			High	0.58	0.06	0.44	0.73
		Random	Low	0.48	0.06	0.36	0.61
			High	0.53	0.07	0.39	0.68
Quadrant Error Rate	Eye-tracking	Event	Low	0.90%	0.30%	0.20%	1.60%
			High	1.70%	0.70%	0.30%	3.20%
		Random	Low	1.30%	0.70%	0.00%	2.90%
			High	1.70%	0.90%	0.00%	3.70%
	Manual	Event	Low	1.80%	0.50%	0.70%	2.90%
			High	2.80%	0.80%	1.00%	4.60%
		Random	Low	2.20%	1.00%	0.10%	4.30%
			High	2.50%	0.60%	1.00%	3.90%
Value Error Rate	Eye-tracking	Event	Low	3.50%	0.90%	1.50%	5.40%
			High	4.50%	1.30%	1.60%	7.50%
		Random	Low	5.10%	1.00%	2.80%	7.40%
			High	5.30%	1.60%	1.80%	8.70%
	Manual	Event	Low	4.00%	1.20%	1.20%	6.80%
			High	3.90%	0.70%	2.30%	5.50%
		Random	Low	4.90%	1.10%	2.50%	7.30%
			High	4.40%	1.00%	2.20%	6.50%
Overall Workload	Eye-tracking	Event	Low	2.40	0.04	1.72	3.08
			High	2.58	0.30	1.92	3.24
		Random	Low	2.11	0.25	1.55	2.66
			High	2.59	0.27	1.98	3.20
	Manual	Event	Low	2.87	0.38	2.02	3.71
			High	3.21	0.35	2.44	3.99
		Random	Low	2.62	0.28	2.01	3.23
			High	2.91	0.27	2.30	3.52

Table 14 (cont'd)

Measure	Control Method	Event Timing	Taskload	*M*	*SD*	95% Confidence Interval *LB*	95% Confidence Interval *UB*
Mental Workload	Eye-tracking	Event	Low	2.82	0.46	1.79	3.85
			High	2.55	0.41	1.63	3.47
		Random	Low	2.64	0.43	1.67	3.60
			High	3.09	0.46	2.07	4.11
	Manual	Event	Low	3.18	0.48	2.11	4.26
			High	3.73	0.45	2.73	4.73
		Random	Low	2.91	0.42	1.99	3.83
			High	3.91	0.42	2.99	4.83
Physical Workload	Eye-tracking	Event	Low	1.46	0.21	0.99	1.92
			High	2.09	0.21	1.62	2.56
		Random	Low	1.82	0.30	1.16	2.48
			High	2.18	0.23	1.68	2.69
	Manual	Event	Low	2.91	0.39	2.04	3.78
			High	3.00	0.51	1.88	4.12
		Random	Low	2.73	0.41	1.82	3.63
			High	2.55	0.41	1.63	3.47
Temporal Workload	Eye-tracking	Event	Low	3.46	0.46	2.44	4.47
			High	3.64	0.39	2.77	4.50
		Random	Low	2.09	0.25	1.53	2.65
			High	3.00	0.38	2.15	3.85
	Manual	Event	Low	3.27	0.57	2.00	4.55
			High	3.91	0.48	2.85	4.97
		Random	Low	2.91	0.42	1.99	3.83
			High	3.00	0.30	2.33	3.67
Performance	Eye-tracking	Event	Low	5.46	0.37	4.64	6.27
			High	5.55	0.37	4.73	6.36
		Random	Low	5.36	0.24	4.82	5.91
			High	5.27	0.33	4.53	6.01
	Manual	Event	Low	5.36	0.28	4.74	5.99
			High	4.91	0.29	4.28	5.53
		Random	Low	5.09	0.29	4.46	5.73
			High	5.09	0.34	4.33	5.85
Effort	Eye-tracking	Event	Low	3.27	0.54	2.07	4.48
			High	3.46	0.46	2.44	4.47
		Random	Low	2.64	0.45	1.63	3.65
			High	3.46	0.47	2.40	4.51
	Manual	Event	Low	3.73	0.57	2.45	5.01
			High	3.82	0.44	2.74	4.89
		Random	Low	3.36	0.47	2.31	4.42
			High	3.73	0.45	2.73	4.73
Frustration	Eye-tracking	Event	Low	1.82	0.33	1.09	2.54
			High	2.27	0.33	1.53	3.01
		Random	Low	1.82	0.23	1.31	2.32
			High	2.09	0.21	1.62	2.56
	Manual	Event	Low	2.46	0.39	1.59	3.32
			High	2.73	0.38	1.87	3.58
		Random	Low	1.91	0.29	1.28	2.54
			High	2.36	0.31	1.67	3.05

Analysis of Variance (ANOVA) Tables per Measure

Table 15. ANOVA: Event Response Time

Source	Sum of Squares	df	Mean Square	F	Sig.
Control Method	**11.110**	**1**	**11.110**	**82.680**	**0.000**
Event Timing	**0.200**	**1**	**0.200**	**12.560**	**0.005**
Taskload	0.011	1	0.011	0.463	0.512
Control Method * Event Timing	**0.168**	**1**	**0.168**	**6.828**	**0.026**
Control Method * Taskload	0.001	1	0.001	0.048	0.831
Event Timing * Taskload	0.081	1	0.081	1.925	0.195
Control Method * Event Timing * Taskload	0.024	1	0.024	0.487	0.501
Error (Control Method)	1.344	10	0.134		
Error (Event Timing)	0.159	10	0.016		
Error (Taskload)	0.231	10	0.023		
Error (Control Method * Event Timing)	0.247	10	0.025		
Error (Control Method * Taskload)	0.125	10	0.013		
Error (Event Timing * Taskload)	0.421	10	0.042		
Error (Control Method * Event Timing * Taskload)	0.491	10	0.049		

Table 16. ANOVA: Switch Time

Source	Sum of Squares	df	Mean Square	F	Sig.
Control Method	**15.540**	**1**	**15.5400**	**140.698**	**0.000**
Event Type	**0.380**	**1**	**0.3800**	**9.986**	**0.010**
Taskload	0.020	1	0.0200	2.677	0.133
Control Method * Event Type	0.009	1	0.0090	2.983	0.115
Control Method * Taskload	0.005	1	0.0050	0.675	0.430
Event Type * Taskload	0.014	1	0.0140	1.042	0.331
Control Method * Event Type * Taskload	0.018	1	0.0180	1.089	0.321
Error (Control Method)	1.104	10	0.1104		
Error (Event Type)	0.039	10	0.0039		
Error (Taskload)	0.074	10	0.0074		
Error (Control Method * Event Type)	0.030	10	0.0030		
Error (Control Method * Taskload)	0.078	10	0.0078		
Error (Event Type * Taskload)	0.132	10	0.0132		
Error (Control Method * Event Type * Taskload)	0.166	10	0.0166		

Table 17. ANOVA: Target Response Time

Source	Sum of Squares	df	Mean Square	F	Sig.
Control Method	0.029	1	0.0290	1.024	0.335
Event Type	**0.065**	**1**	**0.0650**	**13.759**	**0.004**
Taskload	0.005	1	0.0050	1.549	0.242
Control Method * Event Type	0.041	1	0.0410	3.839	0.079
Control Method * Taskload	0.006	1	0.0060	1.212	0.297
Event Type * Taskload	0.027	1	0.0270	2.548	0.141
Control Method * Event Type * Taskload	0.004	1	0.0040	0.362	0.561
Error (Control Method)	0.288	10	0.0288		
Error (Event Type)	0.047	10	0.0047		
Error (Taskload)	0.031	10	0.0031		
Error (Control Method * Event Type)	0.108	10	0.0108		
Error (Control Method * Taskload)	0.053	10	0.0053		
Error (Event Type * Taskload)	0.104	10	0.0104		
Error (Control Method * Event Type * Taskload)	0.117	10	0.0117		

Table 18. ANOVA: Quadrant Errors

Source	Sum of Squares	df	Mean Square	F	Sig.
Control Method	0.002	1	0.0020	2.614	0.137
Event Type	0.000	1	0.0002	0.026	0.875
Taskload	0.001	1	0.0010	1.639	0.229
Control Method * Event Type	0.000	1	0.0000	0.047	0.834
Control Method * Taskload	0.000	1	0.0000	0.000	1.000
Event Type * Taskload	0.000	1	0.0000	0.230	0.642
Control Method * Event Type * Taskload	0.000	1	0.0000	0.070	0.797
Error (Control Method)	0.007	10	0.0007		
Error (Event Type)	0.007	10	0.0007		
Error (Taskload)	0.005	10	0.0005		
Error (Control Method * Event Type)	0.004	10	0.0004		
Error (Control Method * Taskload)	0.006	10	0.0006		
Error (Event Type * Taskload)	0.007	10	0.0007		
Error (Control Method * Event Type * Taskload)	0.003	10	0.0003		

Table 19. ANOVA: Target Response Errors

Source	Sum of Squares	df	Mean Square	F	Sig.
Control Method	0.000	1	0.0000	0.087	0.774
Event Type	0.002	1	0.0020	1.218	0.296
Taskload	0.000	1	0.0001	0.094	0.766
Control Method * Event Type	0.000	1	0.0000	0.233	0.640
Control Method * Taskload	0.001	1	0.0010	0.733	0.412
Event Type * Taskload	0.000	1	0.0000	0.417	0.533
Control Method * Event Type * Taskload	0.000	1	0.0000	0.064	0.805
Error (Control Method)	0.022	10	0.0022		
Error (Event Type)	0.016	10	0.0016		
Error (Taskload)	0.006	10	0.0006		
Error (Control Method * Event Type)	0.006	10	0.0006		
Error (Control Method * Taskload)	0.007	10	0.0007		
Error (Event Type * Taskload)	0.006	10	0.0006		
Error (Control Method * Event Type * Taskload)	0.004	10	0.0004		

Table 20. ANOVA: Overall Workload

Source	Sum of Squares	df	Mean Square	F	Sig.
Control Method	**5.146**	**1**	**5.1460**	**16.672**	**0.002**
Event Type	0.941	1	0.9410	2.413	0.151
Taskload	**2.317**	**1**	**2.3170**	**29.385**	**0.000**
Control Method * Event Type	0.101	1	0.1010	0.469	0.509
Control Method * Taskload	0.001	1	0.0010	0.007	0.934
Event Type * Taskload	0.080	1	0.0800	0.283	0.606
Control Method * Event Type * Taskload	0.180	1	0.1800	2.352	0.156
Error (Control Method)	3.087	10	0.3087		
Error (Event Type)	3.900	10	0.3900		
Error (Taskload)	0.789	10	0.0789		
Error (Control Method * Event Type)	2.154	10	0.2154		
Error (Control Method * Taskload)	1.253	10	0.1253		
Error (Event Type * Taskload)	2.839	10	0.2839		
Error (Control Method * Event Type * Taskload)	0.765	10	0.0765		

Table 21. ANOVA: Mental Workload

Source	Sum of Squares	df	Mean Square	F	Sig.
Control Method	**9.557**	**1**	**9.5570**	**11.489**	**0.007**
Event Type	0.102	1	0.1020	0.177	0.683
Taskload	**4.102**	**1**	**4.1020**	**9.601**	**0.011**
Control Method * Event Type	0.284	1	0.2840	1.359	0.271
Control Method * Taskload	**2.557**	**1**	**2.5570**	**19.397**	**0.001**
Event Type * Taskload	1.920	1	1.9200	2.761	0.128
Control Method * Event Type * Taskload	0.102	1	0.1020	0.194	0.669
Error (Control Method)	8.318	10	0.8318		
Error (Event Type)	5.773	10	0.5773		
Error (Taskload)	4.273	10	0.4273		
Error (Control Method * Event Type)	2.091	10	0.2091		
Error (Control Method * Taskload)	1.318	10	0.1318		
Error (Event Type * Taskload)	6.955	10	0.6955		
Error (Control Method * Event Type * Taskload)	5.273	10	0.5273		

Table 22. ANOVA: Physical Workload

Source	Sum of Squares	df	Mean Square	F	Sig.
Control Method	**18.182**	**1**	**18.1820**	**15.385**	**0.003**
Event Type	0.045	1	0.0450	0.076	0.788
Taskload	**1.136**	**1**	**1.1360**	**6.098**	**0.033**
Control Method * Event Type	**1.636**	**1**	**1.6360**	**6.923**	**0.025**
Control Method * Taskload	1.636	1	1.6360	3.750	0.082
Event Type * Taskload	0.409	1	0.4090	0.732	0.412
Control Method * Event Type * Taskload	0.000	1	0.0000	0.000	1.000
Error (Control Method)	11.818	10	1.1818		
Error (Event Type)	5.955	10	0.5955		
Error (Taskload)	1.864	10	0.1864		
Error (Control Method * Event Type)	2.364	10	0.2364		
Error (Control Method * Taskload)	4.364	10	0.4364		
Error (Event Type * Taskload)	5.591	10	0.5591		
Error (Control Method * Event Type * Taskload)	3.000	10	0.3000		

Table 23. ANOVA: Temporal Demand

Source	Sum of Squares	df	Mean Square	F	Sig.
Control Method	1.136	1	1.1360	1.445	0.257
Event Type	**14.727**	**1**	**14.7270**	**14.336**	**0.004**
Taskload	**4.545**	**1**	**4.5450**	**13.158**	**0.005**
Control Method * Event Type	0.727	1	0.7270	0.879	0.371
Control Method * Taskload	0.182	1	0.1820	0.233	0.640
Event Type * Taskload	0.045	1	0.0450	0.057	0.816
Control Method * Event Type * Taskload	2.227	1	2.2270	2.865	0.121
Error (Control Method)	7.864	10	0.7864		
Error (Event Type)	10.273	10	1.0273		
Error (Taskload)	3.455	10	0.3455		
Error (Control Method * Event Type)	8.273	10	0.8273		
Error (Control Method * Taskload)	7.818	10	0.7818		
Error (Event Type * Taskload)	7.955	10	0.7955		
Error (Control Method * Event Type * Taskload)	7.773	10	0.7773		

Table 24. ANOVA: Performance

Source	Sum of Squares	df	Mean Square	F	Sig.
Control Method	1.920	1	1.9200	1.753	0.215
Event Type	0.284	1	0.2840	0.558	0.472
Taskload	0.284	1	0.2840	0.919	0.360
Control Method * Event Type	0.102	1	0.1020	0.194	0.669
Control Method * Taskload	0.284	1	0.2840	0.401	0.541
Event Type * Taskload	0.102	1	0.1020	0.577	0.465
Control Method * Event Type * Taskload	0.557	1	0.5570	1.047	0.330
Error (Control Method)	10.955	10	1.0955		
Error (Event Type)	5.091	10	0.5091		
Error (Taskload)	3.091	10	0.3091		
Error (Control Method * Event Type)	5.273	10	0.5273		
Error (Control Method * Taskload)	7.091	10	0.7091		
Error (Event Type * Taskload)	1.773	10	0.1773		
Error (Control Method * Event Type * Taskload)	5.318	10	0.5318		

Table 25. ANOVA: Effort

Source	Sum of Squares	df	Mean Square	F	Sig.
Control Method	**4.545**	**1**	**4.5450**	**6.309**	**0.031**
Event Type	1.636	1	1.6360	2.677	0.133
Taskload	**2.909**	**1**	**2.9090**	**12.427**	**0.005**
Control Method * Event Type	0.045	1	0.0450	0.073	0.792
Control Method * Taskload	0.409	1	0.4090	0.557	0.473
Event Type * Taskload	1.136	1	1.1360	2.463	0.148
Control Method * Event Type * Taskload	0.182	1	0.1820	0.879	0.371
Error (Control Method)	7.205	10	0.7205		
Error (Event Type)	6.114	10	0.6114		
Error (Taskload)	2.341	10	0.2341		
Error (Control Method * Event Type)	6.205	10	0.6205		
Error (Control Method * Taskload)	7.341	10	0.7341		
Error (Event Type * Taskload)	4.614	10	0.4614		
Error (Control Method * Event Type * Taskload)	2.068	10	0.2068		

Table 26. ANOVA: Frustration

Source	Sum of Squares	df	Mean Square	F	Sig.
Control Method	**2.909**	**1**	**2.9090**	**4.103**	**0.070**
Event Type	1.636	1	1.6360	2.222	0.167
Taskload	**2.909**	**1**	**2.9090**	**7.111**	**0.024**
Control Method * Event Type	0.727	1	0.7270	0.434	0.525
Control Method * Taskload	0.000	1	0.0000	0.000	1.000
Event Type * Taskload	0.000	1	0.0000	0.000	1.000
Control Method * Event Type * Taskload	0.182	1	0.1820	0.645	0.441
Error (Control Method)	7.091	10	0.7091		
Error (Event Type)	7.364	10	0.7364		
Error (Taskload)	4.091	10	0.4091		
Error (Control Method * Event Type)	16.773	10	1.6773		
Error (Control Method * Taskload)	2.500	10	0.2500		
Error (Event Type * Taskload)	3.500	10	0.3500		
Error (Control Method * Event Type * Taskload)	2.818	10	0.2818		

DISTRIBUTION

	Copies Paper/CD
DoD ACTIVITIES (CONUS)	
DEFENSE TECH INFORMATION CTR 8725 JOHN J KINGMAN RD SUITE 0944 FORT BELVOIR, VA 22060-6218	1/1
INTERNAL	
W	1/0
CX7 (TECHNICAL LIBRARY)	3/1

(THIS PAGE INTENTIONALLY LEFT BLANK)

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION IS UNLIMITED

NAVSEA
WARFARE CENTERS
DAHLGREN